



Proposed River Club Redevelopment

Investigation into the impact of the proposed redevelopment of the River Club on flooding and flood abatement in the Salt River Catchment

Liesbeek Leisure Properties Trust

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*Bringing ideas
to life*

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Document prepared by:

Aurecon South Africa (Pty) Ltd

Reg No 1977/003711/07

Aurecon Centre
1 Century City Drive
Waterford Precinct
Century City
Cape Town 7441
PO Box 494
Cape Town 8000
South Africa

T +27 21 526 9400

F +27 21 526 9500

E capetown@aurecongroup.com

W aurecongroup.com

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Disclaimer

This study was commissioned by Liesbeek Leisure Properties Trust (LLPT) to investigate the impact that their proposed development might have on flooding in the vicinity, downstream and upstream of their property. The City of Cape Town and other affected parties made a number of requests for the modelling to consider a range of alternatives. Aurecon has modelled these with the best available information at the time. The findings of this report should only be used to assess the impact of the River Club Proposal, and cannot / should not be used when considering alternative proposals (e.g. TRUP, NRF, PRASA etc.).



Executive Summary

Introduction

Aurecon South Africa (Pty) Ltd was appointed to undertake a definitive, detailed study of the impact of the proposed River Club development on the potential flooding. This study is intended to be used to guide the decision-making process with respect to the approval, and if successful, the design of the proposed redevelopment of the River Club site. The objectives of this investigation were therefore to determine the following:

- The effect that developing the River Club site would have on the extent of flooding along the Salt and Liesbeek Rivers;
- The implications that any changes to the surface water hydrology might have on flood levels which would affect infrastructure and private property in the vicinity of the Salt and Liesbeek Rivers;
- The cumulative impacts of the River Club development and all other likely / planned developments in the surrounding area; and
- The potential ecological impacts of developing the River Club site – particularly on the Raapenberg wetlands.

The City of Cape Town (City) agreed that reference to other accepted studies would be necessary as these address some of the above-mentioned objectives.

Literature Review

A review of the relevant literature details the following: the history of the site which once formed part of an extensive wetland; the changes to the City's policies; the effects of urban development, climate change and sea level rise; seven recent studies relating to flooding in the Liesbeek / Salt River Catchments; and which currently conceptualised developments are likely to take place in the vicinity of the River Club site. The literature review found that:

- The River Club site is prone to flooding by events with a frequency of recurrence of about once in every 2 to 5 years.
- There are a significant number of recent studies that incorporate the River Club site - some of these studies provide contradictory results.
- There is significant interest in the future development of the River Club site:
 - There are a wide range of stakeholders.
 - There are a variety of contradictory 'visions' of what should, and should not be done.
- There have been changes to the City's policies relating to developing within the floodplain.
- There is concern that infilling of the River Club site will result in significant increases in flood levels.
 - Some stakeholders have openly rejected any study that indicates a negligible or insignificant impact on flood levels.
- There was a need for a detailed analysis of the potential for flooding in the vicinity of the River Club site.



Method of Investigation

To assess the potential impacts of the proposed development on flooding in the vicinity of the site, Aurecon developed a series of PCSWMM and HEC-RAS two-dimensional models. These models were used to determine the existing (status-quo) flooding and the extent of flooding if the proposed development were to be allowed – and thus any changes as a result of the proposed development. A range of development and mitigation scenarios were considered. These include: pre- and post-development flood models; the effect of widening the Salt River Canal; the effect of sediment build up in the channel; the effect of different storm surges; the change in the hazard associated with the flooding; and the sensitivity of the models to different input parameters. As far as possible this analysis has been conservative. Furthermore, it has taken account of the full range of development proposals for the area.

Results and Conclusions

This study has reviewed seven relevant studies, and has undertaken extensive modelling with both HEC-RAS and PCSWMM 2D. The report presents (Chapter 4) the results for each scenario that was considered, without making definitive findings or conclusions due to the complexity of the site. Therefore, it is necessary to consider all the separate findings from the different scenarios together before drawing any definitive conclusions. Considering any ‘question’ or ‘issue’ raised in isolation may lead to a misinterpretation of the results. Furthermore, hydrology and hydraulic modelling should be considered as a tool for analysing potential impacts and scenarios, and as this is not an ‘exact science’, rather engineering judgement and experience is important in interpreting the results. Therefore, Aurecon involved three of its staff who have extensive experience of the circumstances at this site in order to ensure that the analyses were undertaken and interpreted in the most reasonable and appropriate manner.

Based on a review of all the available studies, the extensive modelling, and engineering judgement, it is Aurecon’s opinion (as stated in Chapter 5) that:

- The results (magnitude of impact) appear to be relatively consistent for each study, even where study methods and elevations may differ slightly.
- The development of the River Club, along with the TRUP, PRASA and NRF sites is likely to have an impact on flood levels, in the order of 0.01m – 0.15m depending on the storm recurrence interval and location. The greatest differences in flood levels occur in the vicinity of the South African Astronomical Observatory. The impacts of these changes were deemed to be insignificant.
- Were the River Club to be developed in isolation (i.e. TRUP, NRF, PRASA were not to be developed), then the impacts on flood levels would be of a similar magnitude for all recurrence intervals, but less by approximately 0.00m – 0.03m, than the levels for the scenario where all the proposed developments went ahead. These impacts were also considered to be insignificant.
 - The differences between the post development scenarios are also well within the uncertainties of the modelling tools.
 - It is important to note that if any of the proposed TRUP, NRF and PRASA developments were to be undertaken in isolation, then the results must not be interpreted to mean that they would only have an impact equal to the differences between the post development scenarios for the River Club, TRUP, PRASA, and the NRF sites together, and the post development scenario for the River Club alone – as indicated in the RHDHV Study. This is because of the complexities of the hydrology and hydraulics in the vicinity of the River Club site.
- The design of changes to the Liesbeek Canal should aim to maintain the existing hydraulic functioning of the wetland during smaller recurrence interval events. The current proposal would have little to no effect, but further detailed design refinements – during detailed design – should be reanalysed.
- It would be advisable, in consultation with the Fresh Water Consultant, to consider reversing the intervention undertaken by the TRUPA, Friends of the Liesbeek and the South African Astronomical Observatory (SAAO) – as this is likely to increase flows into the wetland.

- The site is unlikely to be developed by the City as an attenuation facility.
- PRASA should not be allowed to close the existing overland flood route that extends across its property, as this is important for mitigating flood risk – regardless of whether the proposed River Club development proceeds.
- The extension to Berkley Road should be designed in such a manner as to not impact on the water levels determined by this study and any changes to the preliminary design would need to be re-evaluated. The detailed design of the extension of Berkley Road should consider raising the portion of the road that is within the floodplain.
- There is a need to address the localised change in risk along Liesbeek Parkway. This could be done through raising the road locally (as discussed in the report) to eliminate the potential flooding by the 1 in 100-year event, however ponding due to local stormwater is also likely to occur at this location for which the provision of warning signs would probably suffice.
- The impact of the proposed development on flood levels and the areal extent of the additional flooding are considered to be negligible.
- The combined impacts on flood levels of the proposed development together with the proposed development of the Two Rivers Urban Park and their extent are considered to be negligible.
- Widening the Salt River would reduce the flood levels for all scenarios, but as the capital cost would be very high and the benefits very small this is unlikely to be viable in the foreseeable future.

The main conclusion of this study is that the proposed development would have an insignificant effect on flooding in the vicinity of the existing River Club site. Although the development would have some limited localised effects on flows and water levels in the Liesbeek and Black Rivers, the modelled impacts in terms of increased hazard and potential damage to properties are insignificant and can be considered to be negligible – provided that the above-mentioned findings are adhered to.

Although the proposed development would not have a significant impact on flooding, it would none the less require the following deviations in terms of the City's 'Floodplain and River Corridor Management Policy' (CSRM, 2009a):

- Section 9.2: Flood Management and Public Safety
 - Permission to develop / obstruct the free flow of water within the 20-year flood line area would need to be granted.
- Section 10.5: Table 1: Framework for the assessment of Proposals
 - The current assessment framework forbids development (including filling) within the 50-year flood plain. It notes: *"In exceptional circumstances minor "smoothing" of the 50 / 100-year flood line may be considered, provided equivalent compensatory stage storage volume is provided within the development precinct"*.
 - As the proposed development falls under the 50-year flood line, a deviation from the policy, allowing the developer to fill (considered development) would need to be granted.

Although the two development layouts (Section 3.2) would both have similar impacts, Layout Option 1 (focus of this study) would be the preferable option as it aligns with the vision of the City's 'Floodplain and River Corridor Management Policy' (CSRM, 2009a) in that, in comparison to Layout 2) it provides an improved ecological corridor, and the potential for improved amenity and biodiversity in accordance with the principles of Water Sensitive Urban Design (WSUD) principles.

It is recommended that the City should take account of the findings of this study to determine whether in terms of the policy and based on consideration of the *"geomorphological, maintenance, social and economic aspects"* (presented by other specialists) the proposed development of the River Club Site should be approved.



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Abbreviations

1D	One Dimensional
2D	Two Dimensional
AED	African Environmental Development
CC	Climate Change
CMC	Cape Metropolitan Council
CSRM	Catchment, Stormwater, and River Management Branch
DEM	Digital Elevation Model
DSM	Digital Surface Model
DTM	Digital Terrain Model
EGL	Energy Grade Line
EL	Energy Level
GIS	Geographical Information Systems
LIDAR	Light Detection and Ranging
LLPT	Liesbeek Leisure Properties Trust
NRF	National Research Foundation
PRASA	Passenger Rail Agency of South Africa
PRDW	Prestedge Retief Dresner Wijnberg
RH-DHV	Royal HaskoningDHV
RI	Recurrence Interval
RSA	Republic of South Africa
SAAO	South African Astronomical Observatory
TRUP	Two Rivers Urban Park
TRUPA	Two Rivers Urban Park Association
WCG	Western Cape Government
WS	Water Surface Level

Symbols

C	Runoff Coefficient
ha	Hectares
km	Kilometre
km ²	Square kilometres
m	Metre
m ³	Cubic metres
m ³ /s	Cubic metres per second
N	Manning's Roughness



1 Introduction

1.1 Background

The Liesbeek Leisure Properties Trust (LLPT) currently owns and operates the River Club in Observatory, Cape Town (Figure 1-1). LLPT proposes to develop the site as a mixed commercial, institutional, residential site and therefore as part of the scoping study for the proposed development it acquired the services of African Environmental Development (AED) to undertake a flood line determination study and to assess the impacts of the proposed development on the River Club site and surrounding properties. This study considered the flooding in the vicinity of the River Club site as a result of flows in the Salt River Catchment (Figure 1-1) – which drains by the Elsieskraal, Black and Liesbeek Rivers that discharge into the Salt River.

Concurrently, while LLPT's scoping studies were being undertaken, the Western Cape Government (WCG) were undertaking similar studies aimed at developing a spatial development framework for an area known as the Two Rivers Urban Park (TRUP) – shown in Figure 1-1. The TRUP area is predominantly owned by government (City of Cape Town (City) and Western Cape Government) but also includes some privately-owned erven, such as the River Club site.

Following the release of the Draft Scoping Report for LLPT's proposed development a number of queries were raised with regard to AED's study titled "*Flood Line Determination for the Salt and Liesbeek Rivers at the Cape Town River Club, Cape Town, Western Cape Province, RSA*". It was also noted that there were differences in flood levels determined by the studies commissioned by LLPT and by the WCG as well as in the results of previous studies commissioned by CCT – undertaken by Ninham Shand (2003; 2004) and SRK (2013).

In 2016 Aurecon South Africa (Pty) Ltd was appointed by LLPT to undertake a peer review of the AED study. This necessitated a review of the WCG study and of the previous 2003, 2004 and 2013 studies in order to investigate the identified discrepancies. As a result of the review of these studies it was decided, in consultation with LLPT, that it was necessary to undertake further investigations to confirm the extent, if any, of the impact of the proposed development of the River Club site on the flooding of properties in the areas surrounding this site. This study indicated that the proposed River Club development, in isolation, would have an insignificant impact on flood levels and that there were a number of significant differences between these results and the results of both the AED and WCG studies.

In 2017 Aurecon South Africa (Pty) Ltd was appointed to undertake a definitive, detailed study of the implications on flood levels of the proposed River Club development together with the proposed TRUP development.

This report documents the process and findings of the review of the previous flood studies and of the further investigations carried out by Aurecon. The report also describes the additional investigations and provides comment and conclusions about the potential impacts of the proposed development on flooding and inundation of the River Club site and surrounding properties.

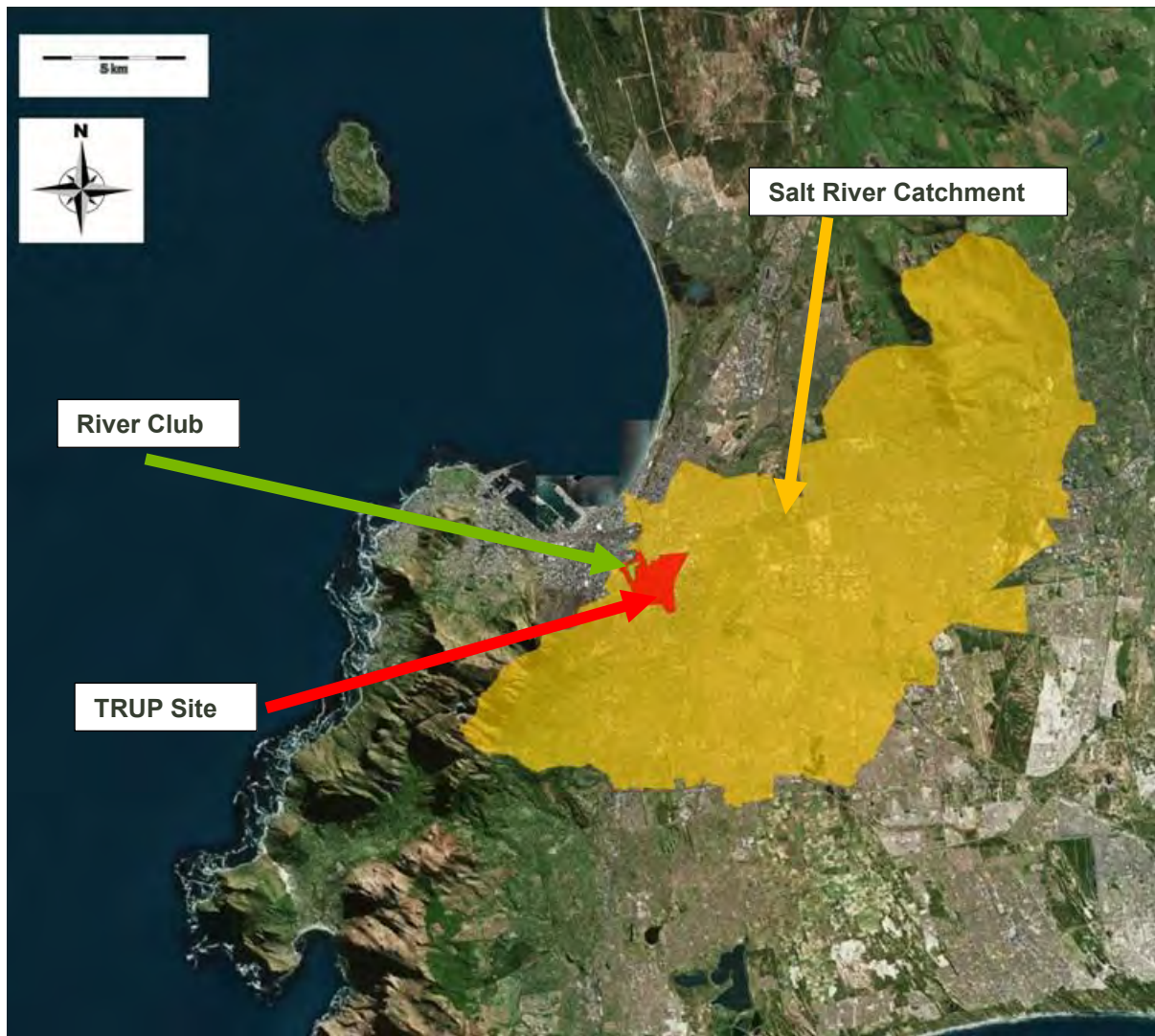


Figure 1-1 Location, and size of the River Club site, within the TRUP area and greater Salt River Catchment

1.2 Objectives

The objectives of this investigation are, *inter alia*, to determine:

- The effect that developing the River Club site would have on the extent of flooding along the Salt and Liesbeek Rivers;
- The implications that any changes to the surface water hydrology might have on flood levels which would affect infrastructure and both public and private property in the vicinity of the Salt and Liesbeek Rivers;
- The cumulative impacts of the River Club development and all other likely / planned developments in the surrounding area; and
- The potential ecological impacts of developing the River Club site – particularly on the Raapenberg wetlands and bird sanctuary.

As agreed with the City, reference to other accepted studies would be necessary to address some of the above-mentioned objectives.



1.3 Limitations

It is important to note that this investigation is based on the City's latest hydrologic models – SRK (2012). Aurecon has previously highlighted concerns about the correctness of this hydrological modelling of various sub-catchments within the catchment area of the Salt River and has made proposals for addressing potential shortcomings. Never the less Aurecon is of the opinion that the Two-Dimensional (2D) models that have been configured for this study provide a reasonable basis for making informed judgements regarding the flood levels for both the pre- and post-development of the River Club site flooding and adjacent areas. This is because the water levels and flow paths determined from the modelling correspond closely with observations by experienced Aurecon employees who visited the sites during major flooding events over the last 15+ years.

2 Literature review

2.1 General background

2.1.1 History of the Salt River Catchment

The histories of the rivers and wetlands in Cape Town are comprehensively documented in Brown & Magoba (2009) and therefore are not repeated in detail here. The histories include the impacts that urbanisation has had on the 'rivers and wetlands' in Cape Town. A literature and internet search of historic images highlighted the changes, over the last century, to the environment in the vicinity of the confluence of the Liesbeek, Black and Salt Rivers. These changes are highlighted in Figure 2-1, Figure 2-2, Figure 2-3 and Figure 2-4, to provide context for this report.

Figure 2-1 shows that historically the Liesbeek and Black Rivers flowed into an extensive wetland. By 1958 this had had changed with the initial canalisation of the rivers as evident from Figure 2-3. In 1960 the (re)canalisation of the Black River took place as well as the creation and canalisation of the Liesbeek Canal along the Eastern boundary of the River Club Site (Whittemore & Gorgens, 2007). By 1968 (Figure 2-3) the impact of urbanisation is clearly evident including a number of changes that impacted on what was previously a more extensive wetland. The last remnants of this once extensive wetland are now known as the 'Raapenberg Wetlands'. The historic presence of an extensive wetland in this area is not surprising, as the area is relatively flat and low lying.

Of interest for this study, is that it is apparent that the course of Liesbeek River changed a number of times between 1937 and the present. Today the abandoned river course is fed by limited runoff from the adjacent urban area, and the majority of the Liesbeek River Catchment's flow is channelled down the Liesbeek River Canal as shown in Figure 2-3 and as evident in Figure 2-4.



Figure 2-1 Aerial footage from 1937 indicating the 'original' course of the Black and Liesbeek Rivers (Richard.F, 2016)

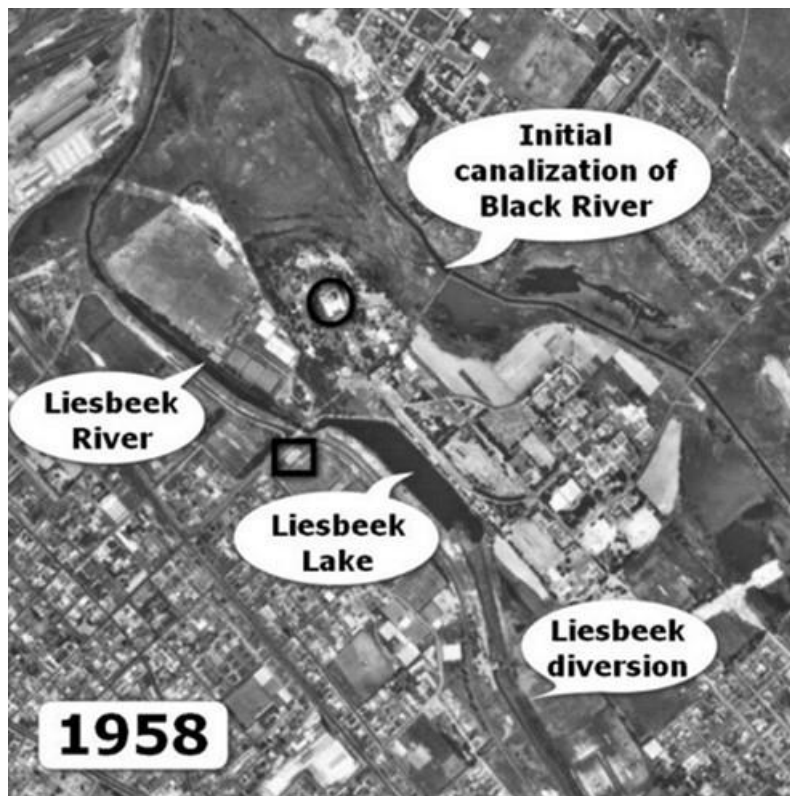


Figure 2-2 Aerial footage indicating the changes between 1937 – 1958 to the course and structure of the Liesbeek and Black Rivers (Richard.F, 2016)

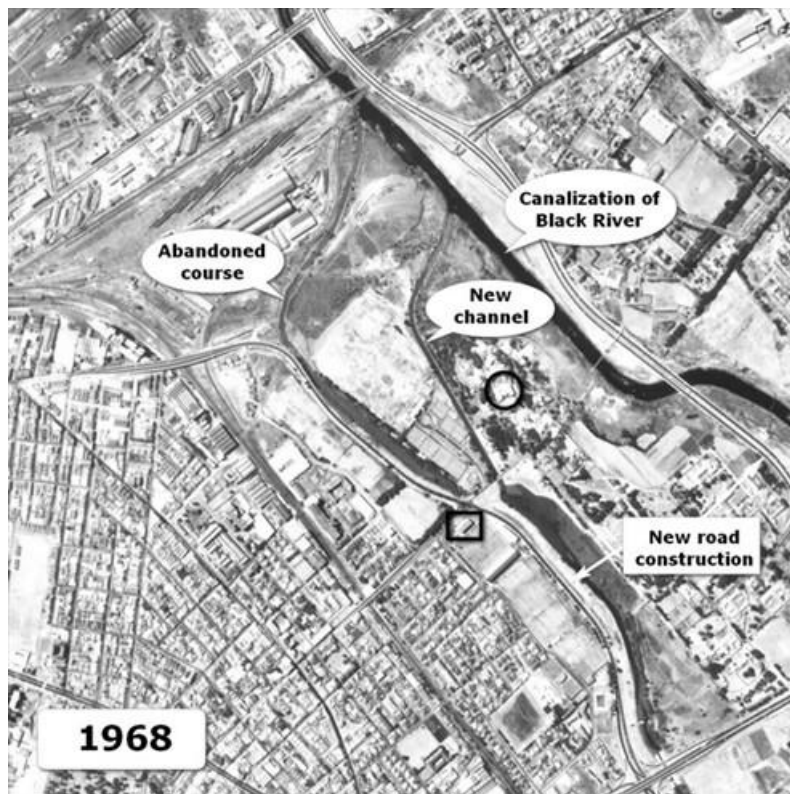


Figure 2-3 Aerial footage indicating the changes between 1958 – 1968 to the course and structure of the Liesbeek and Black Rivers (Richard.F, 2016)

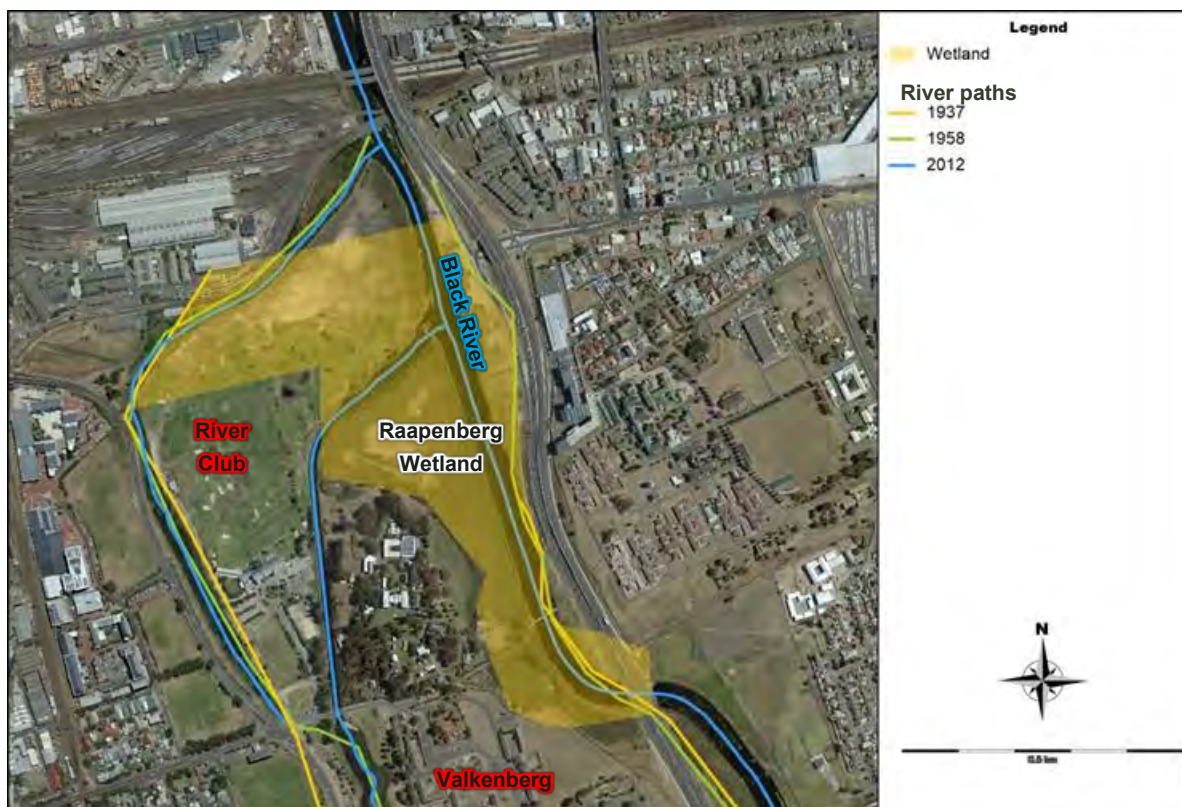


Figure 2-4 Map overlaying the changes between 1937 and the present to the course of the Liesbeek and Black Rivers.


2.1.2 Potential Ecological impacts

The ecological value of the lower reaches of the Liesbeek and Black Rivers is dealt with in a separate report compiled by Dr Liz Day (Freshwater Consulting Group). Dr Day highlighted that the Raapenberg Wetlands (Figure 2-4) are of particular importance and that the change in water depths, particularly for intra-year storm events, was of concern as it may impact on the local fauna and flora. The approach to assessing the impact of the proposed development on the Raapenberg Wetlands is described in Section 3.5.

2.1.3 Policy changes

It is important to recognise that over the last 20 years there have been significant shifts in policy relating to the management of stormwater and flooding in the City. Prior to 2000 general practise was to limit development to above the 50-year flood line (CMC, 2000). ARCUS GIBB (2000) noted that there was no legislation which stipulated whether it was permissible to develop and fill within the 100, 50 or 20-year flood plains; and that the City had no by-laws preventing filling of the 50 year flood plain. Subsequently the City made significant changes to its policies which are presented in the following documents:

- In 2000
 - ‘Development Control Guidelines in Flood Prone Areas’(CMC, 2000)
- In 2003
 - ‘Floodplain Management Guidelines’ (CSR, 2003)

- 
- In 2009
 - ‘Floodplain and River Corridor Management Policy’ (CSRM, 2009a)
 - ‘Management of urban stormwater impacts policy’ (CSRM, 2009b)

The latest two policy documents, published in 2009, provide the basis for the assessment of development plans in regard to stormwater management and flooding, in the City. Together these require the following:

- Development such as that proposed for the River Club site is required to be elevated above the 1 in 100-year flood line.
- Future upstream developments are required to ensure that properties downstream of any such development are not affected, and if downstream properties are affected then the upstream development would not be permitted in terms of the “Framework for assessment of proposals”.
- Future developments are also required to manage their runoff so as to not to increase and preferably to reduce peak flows.

2.1.4 Construction of a berms along the banks of the Liesbeek River

The construction, in September 2013, of berms and infilling along the banks of the Liesbeek Canal by the, then tenant, of the River Club property has been a contentious issue. Cape Argus (2017) reported that *“Friends of the Liesbeek secretary, Francine Becker, said they saw large Ross Demolition trucks dumping soil on the river banks. This activity continued over the weekend and up to 10 large tks loaded with soil were observed driving into the River Club in the space of an hour. It seems the River Club, desperate to deal with flooding, has illegally dumped material in and along the Liesbeek.”* In the same article it is noted that *“Becker said she spoke to a River Club representative, Nick Ferguson, who said it had been decided to cover the bank to make it 'neat and tidy'...'He said he could not wait for authorisation as the soil was available and too expensive to truck in later. The dumped soil would be compacted mechanically and planted with grass.’”*

During the scoping phase of the project it became evident that the construction of the berm in 2013 remains a contentious issue. The extent of infilling for the berm is shown in Figure 2-5. A process with City’s legal section is currently underway concerning the construction of berms along the Liesbeek Canal without authorisation (Construction of a Berm Along the Liesbeek Canal by the River Club, Ref: 16/1/1/11/243).

According to the proponent of the current development proposal, the berm was built by the previous tenant and is not connected to the current ownership. A notice concerning the removal of the berm was issued by the City to the Liesbeek Leisure Club (Pty) Ltd of which the current owners were not directors or shareholders.

It is Aurecon’s understanding that the process is currently ongoing and the results of the development application will be considered in determining the course of any further action.

During the course of this investigation it became apparent that the South African Astronomical Observatory (SAAO) had constructed a berm on the opposite bank to that of the River Club as indicated in Figure 2-6. The construction of this berm appears to have been undertaken without the permission of the City of Cape Town.

For the assessment of the impact of the infilling on the River Club property the status of both berms presents a difficulty in determining the “predevelopment” status quo. Therefore, for this impact assessment it was decided that the worst-case scenario would be considered – i.e. the “status quo” for

which the largest impact on the SAAO would be realised. This is considered to be the case where neither the River Club, nor the SAAO would have constructed berms (i.e. the status quo in 2012).



Figure 2-5 Extent of infilling on site (outlined in green) (Source: Google earth (11/01/2014))



Figure 2-6 Berm on the South African Astronomical Observatory (SAAO) side of the Liesbeek Canal – constructed sometime between 2013 – 2015



2.1.5 Climate Change considerations

'Human interference with the climate system is occurring, and climate change poses risks for human and natural systems' (IPCC, 2014b). Within urban areas, it is generally predicted that the increase in global temperatures associated with climate change will be exacerbated as a result of the urban heat island effect (IPCC, 2014a). Willems et al. (2012) indicate that rainfall intensities are typically expected to be increase by the end of this century (2100) at small urban hydrology scales by between 10% and 60% from historic levels recorded between 1961 and 1990. A recent stormwater master planning report for the City, SRK (2012) indicated that it was necessary to increase the modelled rainfall depth for design storms by 15% to account for changes in the intensity of extreme events. This was based on an analysis of the potential impact that climate change might have on rainfall intensities in Cape Town, and incorporated into this study.

Other expected impacts of climate change are a rise in the global sea level and increased storm intensities. PRDW (2010) undertook a study to provide estimates of the expected storm surge and wave setup corresponding 1:20 year, 1:50 year and 1:100-year frequencies and provided best and upper estimates of sea level rise in 2035 and in 2060. It was agreed with the City that the levels provided by PRDW (2010), and used for Royal Haskoning DHV's (RH-DHV's) (2017) investigation of the TRUP site, should be used for the current investigation.

2.1.6 The effect of further urbanisation / changes in land-use within the greater Salt River Catchment


Urbanisation typically results in an increase in the impervious surface area, which has significant impacts on a watershed's hydrology (Shuster et al., 2005; CSIR, 2005; Leopold, 1968; Walsh, 2000). Leopold (1968) noted that the volume of runoff is primarily determined by the soil's infiltration characteristics. The increase in the impervious area associated with urbanisation results in greater volumes of runoff and higher peak flows. Urbanisation can also result in significant changes in how runoff is conveyed in most urban areas (Marsalek et al., 2006). Historically, natural channels have often been replaced with hydraulically highly efficient concreted channels. While the increase in impervious areas results in increased runoff volumes, Fletcher et al. (2008) highlighted that 80% to 90% of the increase in peak flows can be attributed to the nature of the conveyance network. The impacts of possible uncontrolled and unmanaged urbanisation are also important.

Long-term catchment planning and management is the responsibility of the City, and not the developers of individual sites within a catchment that is significantly larger than the individual sites. In the case of the River Club the area of the site is less than 0.1% of the area of the Salt River Catchment. The City has, fortunately, been progressive in implementing two critical policies to manage the impact of urbanisation and densification on flooding within the City. These are the City's *'Floodplain and River Corridor Management Policy'* (CSRM, 2009a) and *'Management of urban stormwater impacts policy'* (CSRM, 2009b) – as discussed above.

This report describes the determination of the impacts that the proposed development is expected to have on properties in its vicinity – in accordance with the policies discussed in Section 2.1.3.

2.1.7 Flooding in urban areas

It is important to recognise that not all flooding in an urban area is necessarily related to the flows in a nearby river. The piped underground stormwater system is typically sized for smaller recurrence interval events (typically for flood magnitudes smaller than the 1 in 2-year, 1 in 5-year and 1 in 10-year events – depending on the design criteria) (CSIR, 2005). It is usually planned that during larger storm events (with flood magnitudes greater than the 1 in 2-year, 1 in 5-year or 1 in 10-year events –



depending on design criteria) the excess flows will discharge overland via the road network which is intentionally designed to serve as part of the surface drainage system (CSIR, 2005). While this may be considered as ‘flooding’, it is intentional and not related to the flooding caused by flows in a nearby river – in this case the Liesbeek and the Black/Salt Rivers.

Additionally, for small storm events, should the stormwater infrastructure (inlets and/or pipes) become blocked it is expected that stormwater will be conveyed via the road network – which may appear to be flooding but is often unrelated to the flow in the river.

2.1.8 Perceptions about flooding

In the public discourse – both in media articles and comments submitted as part of the EIA process – there appears to be a perception that the River Club site frequently floods and that the development of the site “will” have an impact on the flooding of properties in the surrounding area – with some interested and affected parties ‘rejecting’ any studies that do not indicate this. While it is correct that the site has flooded relatively frequently (every few years) in recent history – as discussed in Section 2.3 – it is important to differentiate flooding as a result of high runoff, and flooding that results due to the capacity of the drainage system being limited due to inadequate maintenance and or structural failure.

One specific question that will not be answered by the modelling and analysis is “Why it is necessary for the River Club to raise itself out of the floodplain, whilst it is not necessary for the surrounding areas to be raised above the floodplain (TRUP Assoc, 2017).” This is an important question as it implicitly suggests that if the River Club’s proposed development takes place this will worsen the flooding affecting properties that have already been developed, and that if the River Club is not developed these properties will not be affected by flooding. Furthermore, it has been suggested that if the proposed development of the River Club is unaffected by flooding this will increase the impact of flooding of the surrounding properties. It is therefore important to note:

- The reason that there are properties developed on land lower than the existing flood lines is that historically (see Section 2.1.3) properties were allowed to be developed within the 100-year flood plain. Therefore, properties such as those identified as being below the 100-year flood line would, if developed today, be required to elevate themselves out of the floodplain – as is being required for the proposed development on the River Club site.
- The purpose of this report is to assess the impact that the proposed development will have on surrounding properties, in accordance with the provisions of the City’s ‘*Floodplain and River Corridor Management Policy*’ (CSRM, 2009a).

2.2 Previous investigations

The River Club and surrounding areas have been the focus of a number of hydrological and hydraulic studies over the last 20 years. These include the following studies: ARCUS GIBB (2000), Ninham Shand (2003 and 2004); SRK (2012); AED (2016) and RH-DHV (2016). Table 2-1 shows the flood levels determined by these studies at the various locations in the vicinity of the River Club shown in Figure 2-7.

There has been a lack of consistency in the modelling methods and in the resolution at which the upstream catchment area has been modelled. In addition, the more recent models have incorporated climate change considerations. Therefore, undertaking comparisons between the different results is not directly possible. On the other hand, it is evident from Table 2-1 that there are inconsistencies in the results of the various studies. An overview of each of these flood line determinations and other relevant investigations is provided below.

There have also been a number of academic research projects that have considered aspects related to flooding of the River Club Site. These include Lurie (1954), Giermek (2015) and Fisher-Jeffes (2015).

All the above-mentioned studies are briefly described below.



Figure 2-7 Locations at which flood levels are compared in the table below

Table 2-1 Flood levels determined / used in different studies

Report	Year	Climate Change		1:100 Year Storm Event – Water Surface Elevation (mamsl)		
		Increased Rainfall	Increased Sea Level	Location 1	Location 2	Location 3
ARCUS GIBB ¹	2000			Approximately 5.45-5.55m (50 year)		
Ninham Shand ²	2003/2004			4.26	4.45	Flooded
SRK ²	2012	✓	✓ ⁵	4.54	4.95	Flooded
AED ³	2016	✓		5.40	5.40	Flooded
Royal HaskoningDHV ⁴	2017	✓	✓	4.45	4.55	'Limited'

¹ARCUS GIBB refers to the City as having provided these levels, the source of the levels are not clear. ²Hec-Ras Model, ³Spreadsheet based model developed by AED, ⁴PCSWMM 2D Model, ⁵ The study considered both current sea level and sea level rise due to climate change. The model made available by CCT for this investigation did not include sea level rise.

2.2.1 ARCUS GIBB (2000)

In 2000 ARCUS GIBB was appointed by the then tenant of the 'River Club' to prepare a report '*giving details relating to flood levels, options for detention ponding and mitigating measures to reduce the impact of the proposed development on the flood conditions.*' ARCUS GIBB determined 1 in 50-year flood levels of between 5.4 mamsl and 5.5 mamsl. While the more recent studies do not show significant differences in the flood levels between the 1 in 50-year and 1 in 100-year events, it is evident that the flood levels determined by the ARCUS GIBB (2000) study are significantly higher than those determined all other studies except the AED (2016) study. Unlike the AED (2016) study it is not possible to determine how these flood levels were determined by ARCUS GIBB.

2.2.2 Ninham Shand (2003)

As part of a study commissioned by the City and undertaken with input from a number of consulting engineering companies, Ninham Shand developed flood lines for the Black and Salt Rivers (including the area surrounding the River Club site). This was done with input from BKS who undertook the hydrological modelling and the determination of flood lines for the Liesbeek River Catchment. Ninham Shand's flood line determination indicated that:

- For large recurrence interval storm events (i.e. greater than the 1:20 year event) flooding would occur over the PRASA site.
- The fields adjacent to the old Liesbeek River would be flooded.
- The peak flow in the Liesbeek River (as determined by BKS) is approximately 160 m³/s for the 1:100 year recurrence interval flood event.
- The peak flow from the Salt River Catchment, including the Liesbeek River Catchment is approximately 240 m³/s for a 1:100 year recurrence interval storm event.

2.2.3 SRK (2012)

As part of a study commissioned by the City, titled "Stormwater Infrastructure Asset Management Plan (Phase 2A) Rainfall Analysis and High-Level Master Planning", SRK developed both hydrological and hydraulic models for the Salt River Catchment (including the Liesbeek River Catchment). It is worth noting the following:

- The models considered the impact of climate change on rainfall and sea level rise.
- The modelling was undertaken in one dimension (1D) making use of PCSWMM (hydrology and basic hydraulics) and HEC-RAS (hydraulics for flood line determination).
- It is unclear whether Energy Levels or Water Surface Levels were used in determining the flood lines. Communication with the City and a review of the HEC-RAS models indicated the likelihood that Energy Levels were used. This is significant as PCSWMM, the City's choice for modelling the site in 2D does not report Energy Levels directly.

Flood lines determined in this study have been adopted by the City's Stormwater and Sustainability Branch as those to be used for planning purposes. As such, the 2012 SRK study supersedes the 2003 and 2004 Ninham Shand studies.

2.2.4 Giermek (2015)

As part of a Master Degree research project Giermek (2015) undertook an investigation of the benefits of the attenuation provided by the Valkenberg wetlands immediately upstream of the River Club site. The study found that the wetland (+ 2 hectares) was most effective at attenuating rainfall events with *“sudden spikes in peak flow, where a 42 per cent reduction of peak flow was observed. For a scenario with lower flow rates yet a prolonged peak flow rate, the wetland was less effective, with a 20 per cent reduction observed.”* It is important to note that the model for this study was not calibrated and only considered three rainfall events, all in 2013.

2.2.5 Fisher-Jeffes (2015)

Fisher-Jeffes (2015) undertook an investigation of the viability of rainwater and stormwater harvesting in the residential areas of the Liesbeek River Catchment, City of Cape Town. The study focused exclusively on the Liesbeek River Catchment and did not consider the effect of the greater Salt River catchment on the River Club Site. While the study indicates that stormwater harvesting (SWH) throughout the catchment (in a decentralised manner) may have the potential to significantly attenuate peak flows and flooding in the catchment, this does not necessarily equate to the same benefits being experienced if stormwater harvesting / attenuation were to take place on the River Club Site. The study only assessed storms with recurrence intervals of less than 1 in 20 years. Furthermore, the study noted that a decentralised approach to attenuating stormwater would not be practical (to retrofit the catchment at this point) as, apart from the open space at the River Club (which would require a centralised approach) it was shown that the majority of the remaining open space is either not situated in areas where it could be used for SWH – i.e. at the edge of the catchment – or is used for other purposes such as school sports fields. Thus, the study recommended SWH be considered at the planning stage of any future settlement.

2.2.6 AED (2016)

LLPT appointed African Environmental Development (AED) to undertake a flood line determination study as part of the scoping study for the proposed development. LLPT subsequently appointed Aurecon to review the AED study. The review indicated the following:

- The results of AED's hydrological analyses were significantly more conservative than any of the other studies with the 1:100-year storm event having a peak flow of 336 m³/s. The other studies indicated a 1:100-year peak flow of approximately 250 m³/s. AED's peak flows for lower recurrence interval storm events are also higher than those of the other studies. The difference in flow rates between the AED study and other studies is a result of the methods used for runoff determination and routing of the runoff through the catchment.
- AED used an in-house developed spreadsheet based model for determining flood levels. The spreadsheet utilised seven river channel / floodplain cross-sections and took account of bridge backwater effects by increasing channel roughness coefficients at bridge locations. The spreadsheet did not take tidal effects or sea level rise due to climate change into account. The higher AED flow rates and the coarser spreadsheet based determination of flood levels resulted in higher flood levels for all recurrence interval events. In the case of the 1:100-year event, the AED flood levels are between 0.5m and 1.0 m higher than those of the other studies.
- The configuration of AED's hydrological and hydraulic models made it difficult for AED to respond to queries regarding the impact of the proposed development on surrounding areas during lower order flood events (i.e. the annual, 2 year and 5-year events). Also, the effects of tides and sea level rise on flood levels at the River Club site could not be accurately assessed in the spreadsheet model.
- AED identified, as did previous studies, a need to maintain the overland flow route through the PRASA owned land.

2.2.7 RH-DHV (2017)

As a part of the planning for the development of the TRUP area by the Western Cape Government (WCG), Nisa Mammon & Associates (NM&A) was appointed to provide professional services as part of this project. RH-DHV were appointed by NM&A to provide various specialist services, which included the assessment of flooding and flood mitigation measures in the TRUP area. A review of their analysis models and study reports indicated that RH-DHV:

- Made use of the City's existing SWMM stormwater models (i.e. the SRK 2012 models) to provide the hydrology for the investigation.
- Modelled potential flooding in the TRUP area using a 1D-2D approach.
- Had expressly indicated their preference for the use of the HEC-RAS model for undertaking the work, however the City had indicated their preference for the use of PCSWMM.
- Did not identify any flooding over the PRASA site, nor flooding of the fields adjacent to the old Liesbeek River using their base line models.

Aurecon reviewed the RH-DHV models, and identified possible improvements. Following a request from Mr Gerhard Gerber (WCG's TRUP Project Manager), these concerns were conveyed to the TRUP project team. Aurecon and RH-DHV then engaged on the approaches and technical aspects of the RH-DHV models. RH-DHV subsequently revised their model (Model D1). The engagement and results are detailed in Hirschowitz (2017). The results indicated that the revisions to the models increased the 1:100-year flood level by approximately 0.5 m near the River Club, indicating that flooding would occur over the PRASA site, and that flooding of the fields adjacent to the old Liesbeek River would occur. This brought the flood levels determined by RH-DHV in line with those of the other studies.

The TRUP study as a whole has not yet been finalised, however for the purpose of this report the focus is on the RH-DHV: Task 2 Final Report - Modelling of Flood Mitigation Options on the Salt River.

2.2.8 Conclusions based on the review of recent studies

The review of the above studies revealed that the Ninham Shand (2003) study predicted the lowest 1:100 flood levels in the vicinity of the River Club site. This is expected as the study predated the availability of climate change data for rainfall and sea level rise and thus did not consider these circumstances. Considering that the impact of sea level rise on flood levels at the River Club was not found to be significant, and that the effect of climate change on rainfall is an approximate 15% increase in total storm volume, the difference in flood levels between the Ninham Shand (2003) study and the subsequent SRK (2012) study is considered to be reasonable.

Given the differences in hydraulic modelling methods between the SRK (2012) and the RH-DHV (2017) studies (i.e. 1D modelling in the SRK study and 2D in the RH-DHV study), the differences in the predicted flood levels are also reasonable.

The AED study (2016) predicts the most conservative flood levels which are between 0.5 m and 1 m higher than those of the other studies for the same recurrence interval floods. The methodologies and software used for the AED study are considered to be too simplistic for the complexities of a system of this nature which makes justification of the results difficult. It was also difficult for AED to respond to the more detailed modelling requirements of City (i.e. assessment of lower order flood events, tidal effects and sea level rise).

2.3 Recorded flood events

The available records for the last 17 years shown in Figure 2-8 indicate that there have been approximately 7 occasions when the River Club Site was inundated with water – generally considered ‘flooded’. This is not surprising as most modelling indicates that any event greater than about the 1 in 2-year flood event is likely to result in flooding – depending on the spatial and temporal distribution of the storm event in the catchment. Therefore ‘roughly’ it is not unreasonable to expect a number of storm events to have resulted in flooding on the site in the past 17 years. It is worth highlighting that:

- Four of these events take place in a five-year period between 2007 and 2012. During this period the lower reaches of the Liesbeek River shown in Figure 2-9 were partially obstructed due to a structural failure in the canal wall and a lack of maintenance. These partial obstructions resulted in a reduced capacity in the canal and likely increased the depths of flooding during this period. While the frequency of these events highlights the need to maintain / rehabilitate the canal when failures occur, it would be misleading to incorporate them into a frequency analysis.
- The recurrence interval of a storm event does not imply that it occurs on a regular basis. A five-year storm does not take place once every five years – it could happen 5 years in a row and then not again for the next 20 years.

Therefore, it is Aurecon’s opinion that the flooding on the site is consistent with the modelling to date of floods with a frequency of recurrence of about once in every 2 to 5 years.

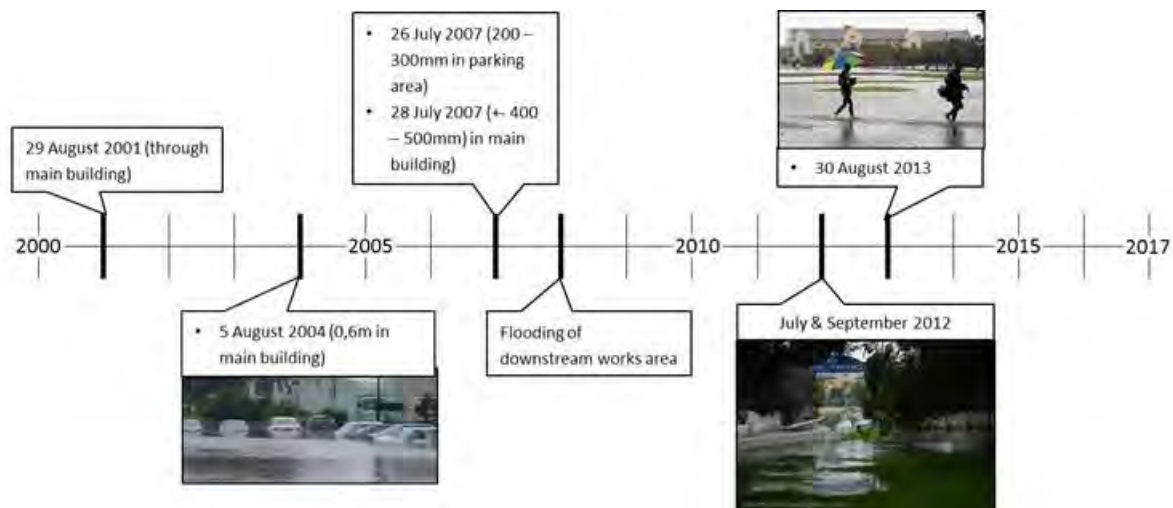


Figure 2-8 Timeline of recorded floods in the vicinity of the River Club



Figure 2-9 Partial obstructions in the Lower Liesbeek River between 2007-2012

2.4 Future development scenario's

2.4.1 TRUP

The Two Rivers Urban Park (TRUP) Programme is an initiative resulting from a partnership between the City and the Western Cape Government (WCG). The intention is to enhance the area's natural and cultural resources while concurrently developing the TRUP area for residential, commercial, institutional, manufacturing and recreational activities, aimed at generating a wide range of housing, recreation, business and employment opportunities, with the aim of creating an '*open opportunity society for all*' so that people can live lives that they value.

Following extensive work undertaken primarily by NM&A, a concept for future development of the TRUP was developed in order to make a preliminary assessment of the capacity of services in the area as indicated in Figure 2-10. Although the TRUP development proposals are not yet available, this conceptual layout provides a good indication of the potential spatial extent of TRUP. It should be noted that the developable area (on the River Club site) according to the TRUP 'vision' is significantly less than that proposed by LLPT for the development of this site.

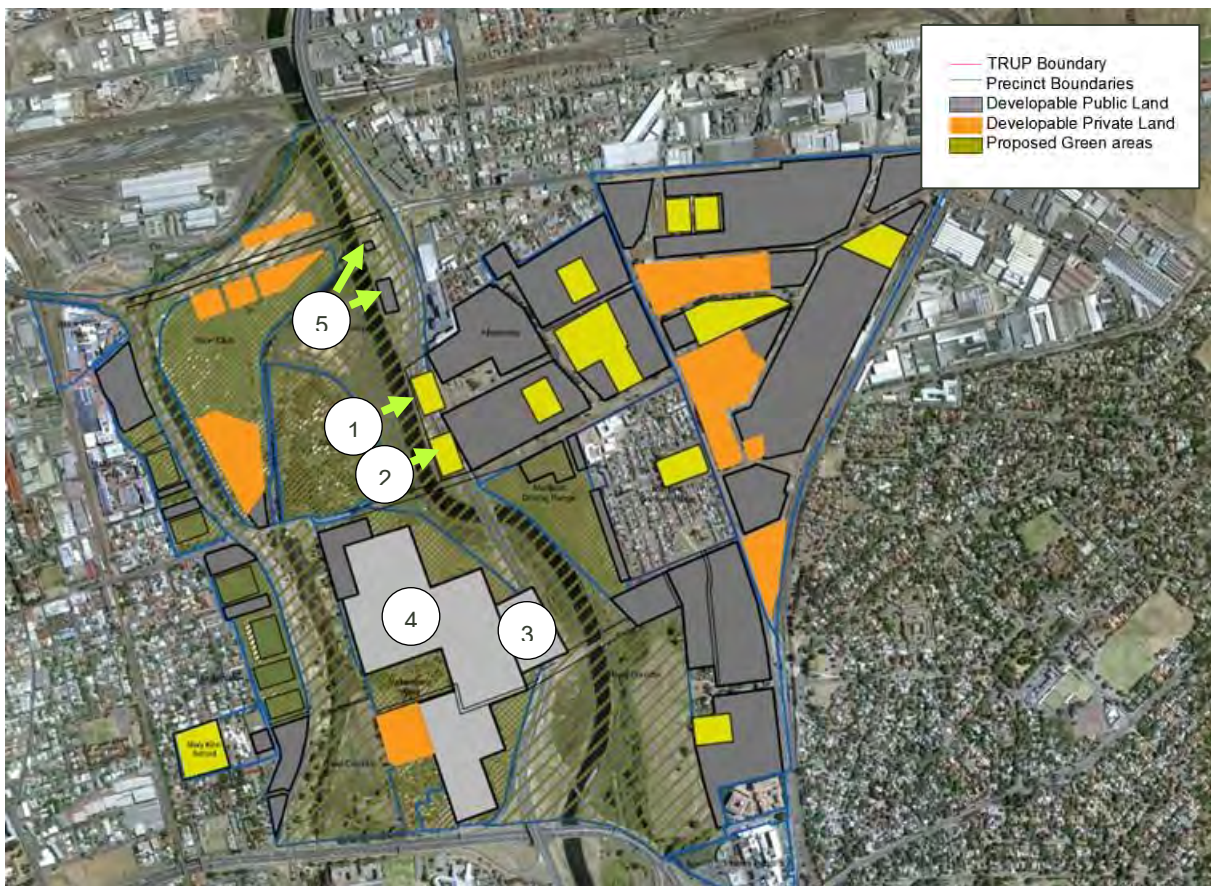



Figure 2-10 Proposed TRUP Layout indicating developable area's

2.4.1.1 Comments on the concept design

Aurecon raised a few queries with regard to the existing concept design and the impact it may have on the flood plain. These questions, and answers, included:

- Whether the proposed open space (No. 1 & 2 in Figure 2-10) will go ahead as they overlay the existing M5?
 - Mammon (2017) noted that these areas are part of a long term landscape scenario to deck over the M5. Mammon (2017) further noted that it is highly unlikely to be implemented in the short to medium term but potentially could be considered in the next 50 + years. Mammon (2017) concluded that *"It is an idea and not a realistic proposal for where we are at as a government and city."*
 - Aurecon would agree it is unrealistic and therefore has not incorporated it into the modelling.
- Whether the developable land (No. 3 in Figure 2-10) will be limited to the South West and not cross the road as it currently does / the road will not be moved nearer to the river?
 - Mammon (2017) noted that the response here is similar to that above.
 - Aurecon allowed for this development, assuming the road could move – even if it is unlikely – as this would potentially affect the floodplain.
- Whether there is an intention to develop areas such as No.4 in Figure 2-10?
 - Mammon (2017) noted that the intention is to develop the Valkenberg Hospital Site in the long term notwithstanding the fact that this site has upgrade plans in place. The dark grey corner portion can be considered for development in the medium term.

- 
- What is the intention regarding the development of the two pieces of land labelled as No.5 in Figure 2-10, as depending on how these are to be developed and linked to the surrounding areas, they could have a significant impact on the floodplain?
 - Mammon (2017) noted that these areas have been identified for the proposed docking feature associated with an information centre and a small-scale restaurant/coffee shop. These areas are dealt with comprehensively in the TRUP Specialist Study: Watercourse Management & Creating a Docking / Waterfront Feature.

2.4.1.2 Conclusions of the RH-DHV Report

The following comments are made with regard to the RH-DHV: Task 2 Final Report - Modelling of Flood Mitigation Options on the Salt River:

- During January 2017 Aurecon had the opportunity to review and comment on the RH-DHV model. The comments made, and responses, are documented in Hirschowitz (2017). Importantly, the subsequent adjustments had a significant impact on the results of the analyses and as such it is worth noting the following:
 - Not all the models were rerun.
 - Not all the suggested changes were made.
 - Aurecon did not review the models prior to their finalisation.
- The City views the RH-DHV study as a high-level planning study that sought to address the key challenges and to identify options for possibly reducing / attenuating peak flows. While the study provided some insight into the potential flood levels, both the report and the City recognised that more detailed studies – such as the current study described in Section 3 – would be required to address local / specific questions.
- RH-DHV had a number of concerns relating to the use of PCSWMM2D and advised the City not to use PCSWMM for any further 2D Hydraulic Modelling.
 - It is Aurecon's view that PCSWMM2D provides a useful tool for assessing flooding in an urbanised area. While HEC-RAS may be better suited for modelling the river hydraulics, it is unable to model the greater stormwater network, surcharging and runoff trapped at low points.
 - PCSWMM 2D has been tested by CHI using the, now standardised, 'Benchmarking the latest generation of 2D hydraulic modelling packages (Neelz & Pender, 2013)' tests. The results indicated that PCSWMM2D performed relatively well in comparison with fully 2D models for other catchments.
 - PCSWMM2D has been utilised for 2D modelling in a range of catchments around the world.

On account of RH-DHV's concerns regarding PCSWMM2D, the 'Status Quo' has been modelled both with both PCSWMM2D and HEC-RAS 2D. The results are discussed in Section 4.

2.4.2 PRASA

The Passenger Rail Agency of South Africa (PRASA) currently intends to further develop its site to the North of the 'Old' Liesbeek River – Figure 2-11. Although significant additional development is proposed, this is not expected to have any effect on the flooding of the Liesbeek/Salt Rivers. It is important to note that there is an overland flood route over the PRASA land, which might be blocked by the proposed PRASA development and result in ponding. This would be the case regardless of any development on the River Club site.

AED (2016) and RH-DHV (2016) discussed the proposed closing by PRASA of the flood route. In this regard the following should be noted:

- It is generally agreed that this would cause flooding upstream; and
- The City would not knowingly allow PRASA to close the flood route. The City has already prevented this happening on one occasion, and an extensive study would be required before a departure from the City's policy would be granted.

The impact of closing this flood route is none the less assessed as part of this study.

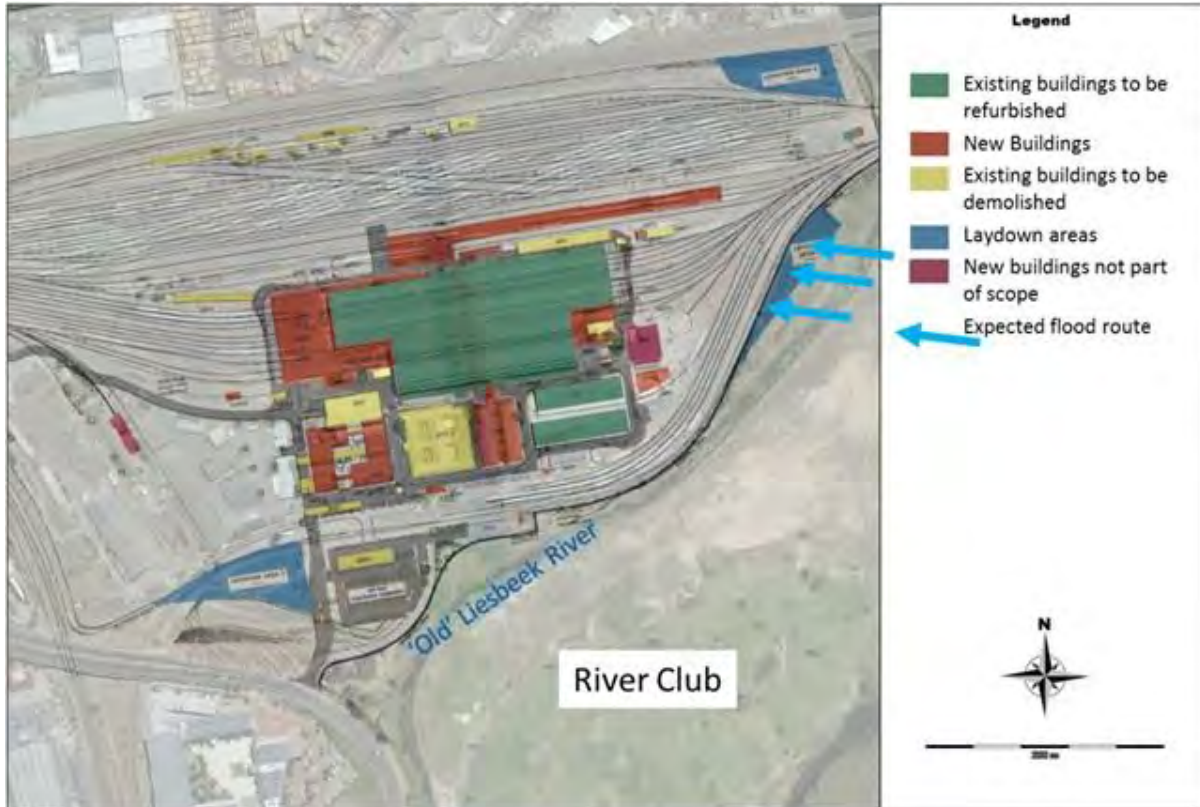


Figure 2-11 Existing PRASA development proposal

2.4.3 NRF

The National Research Foundation (NRF) owns the land at the South African Astronomy Observatory and at the entrance to the River Club (Erf 26423 RE, 26426 and 151833 (26423)) shown in Figure 2-12. The NRF currently intends to develop ERF 151833. As for the proposed River Club site, any development would need to consider the potential impacts on flooding both upstream and downstream. The NRF is also an important stakeholder as there is concern that the proposed development would affect flooding of the Observatory site (ERF 26423 RE). For this analysis, it has been assumed that an office building for the SKA will be constructed on Erf 151833 and a parking area on Erf 26426 as indicated in Figure 2-13.



Figure 2-12 NRF owned land in the vicinity of the River Club



Figure 2-13 Existing NRF development proposal



2.5 Summary of literature review

The above review of the available literature indicates that:

- The River Club site is prone to flooding by events with a frequency of recurrence of about once in every 2 to 5 years (however as noted above it was not possible to undertake a statistical analysis with the available data).
- There are a significant number of studies that incorporate the River Club site.
 - Some of these studies provide contradictory results.
- There is a significant interest in the future development of the River Club site.
 - There are a wide range of stakeholders.
 - There are a variety of contradictory ‘visions’ of what should, and should not be done.
- There have been changes to the City’s policies relating to developing within the floodplain
- There is concern that infilling of the River Club site will result in significant increases in flood levels.
 - Some stakeholders have openly rejected any study that indicates a negligible impact on flood levels.
- There is a need for a detailed analysis of the potential for flooding in the vicinity of the River Club site.



3 Methods of Investigation

3.1 Hydrology & Hydraulic parameters

For the purposes of this investigation it was assumed that the currently accepted hydrological and hydraulic data for the greater Salt River catchment, as incorporated in the SRK (2012) PCSWMM and HEC-RAS models, and provided to Aurecon by the City, are correct. Within the detailed modelling area (the study area), the SRK/City models were interrogated and where inconsistencies and/or inaccuracies were identified these were rectified based on the available data. Although considerable effort was taken to improve the data it is possible that all the errors were not identified.

3.1.1 Hydrological parameters

It is important to note that the City's '*Floodplain and River Corridor Management Policy*' (CSRM, 2009a) refers to the '1:100 year flood'. While it is generally assumed that the 1:100-year flood event is synonymous with the 1:100-year rainfall event, this is not always the case. Several factors affect the relationship between rainfall and runoff, including: the extent of rainfall in a catchment, antecedent soil moisture conditions and the size and shape of the catchment. For the purposes of this study and in accordance with City's requirements, the 24-hour 1:100-year SA SCS Type 1 design rainfall event, adjusted to allow for climate change in accordance with SRK (2012), was used to simulate events with recurrence intervals of between 1 in 2 years and 1 in 100 years.



As noted above, all the remaining catchment / hydrologic parameters used in the SRK (2012) models were adopted.

3.1.2 Manning's roughness

The increased resolution of modelling of the hydraulic system (rivers and stormwater network) for the current study necessitated the reassessment of the roughness parameters assumed for the area that was modelled. The roughness coefficients used for modelling in this study were based on the following: a site inspection; a review of relevant literature shown in Table 3-1; a review of SRK (2012); and a review of the roughness coefficients used in the RH-DHV (2017) study. It was decided to use a Manning's coefficient of 0.015 for all stormwater pipes. The Manning roughness coefficients used for channels and for flood plains are shown in Figure 3-1.

The selection of Manning's Roughness coefficients was further checked against those advised by the Kruger & Gomes (2007).

Table 3-1 Typical Manning's Roughness used in modelling

Component	Suggested Manning's roughness range	Typical condition
Storm water pipes & Culverts	0.010-0.014 (Brunner, 2010) 0.010-0.015 (Brown et al., 2013) 0.011-0.015 (Rossman, 2008) <u>Laboratory tests</u> 0.010-0.011 (Brown et al., 2013)	The use of 0.01 was deemed too low and more representative of laboratory conditions. It is likely that the effective roughness in the stormwater pipes is higher than the selected value. This would have the effect of attenuating peak flows. As such an "average value" was selected.
Overbank roughness (1D Modelling)	Earth channel straight and uniform covered with grass some weeds: 0.022-0.033 Earth channel winding and sluggish covered with grass some weeds: 0.025-0.033 Short grass: 0.025-0.035 High grass 0.03-0.05 (Brunner, 2010)	
Floodplains (2D Modelling)	Short grass: 0.025-0.035 High grass 0.03-0.05 (Brunner, 2010; Hamill, 1995)	
Concrete channels (1D and 2D modelling)	Concrete float finished: 0.013-0.016 (Brunner, 2010) Concrete channel: 0.011-0.02 (Rossman, 2008)	
Grassed Channels / Channel formed by Levees (1D and 2D Modelling)	Earth channel straight and uniform covered with grass some weeds: 0.022-0.033 (Brunner, 2010) Earth channel winding and sluggish covered with grass some weeds: 0.025-0.033	

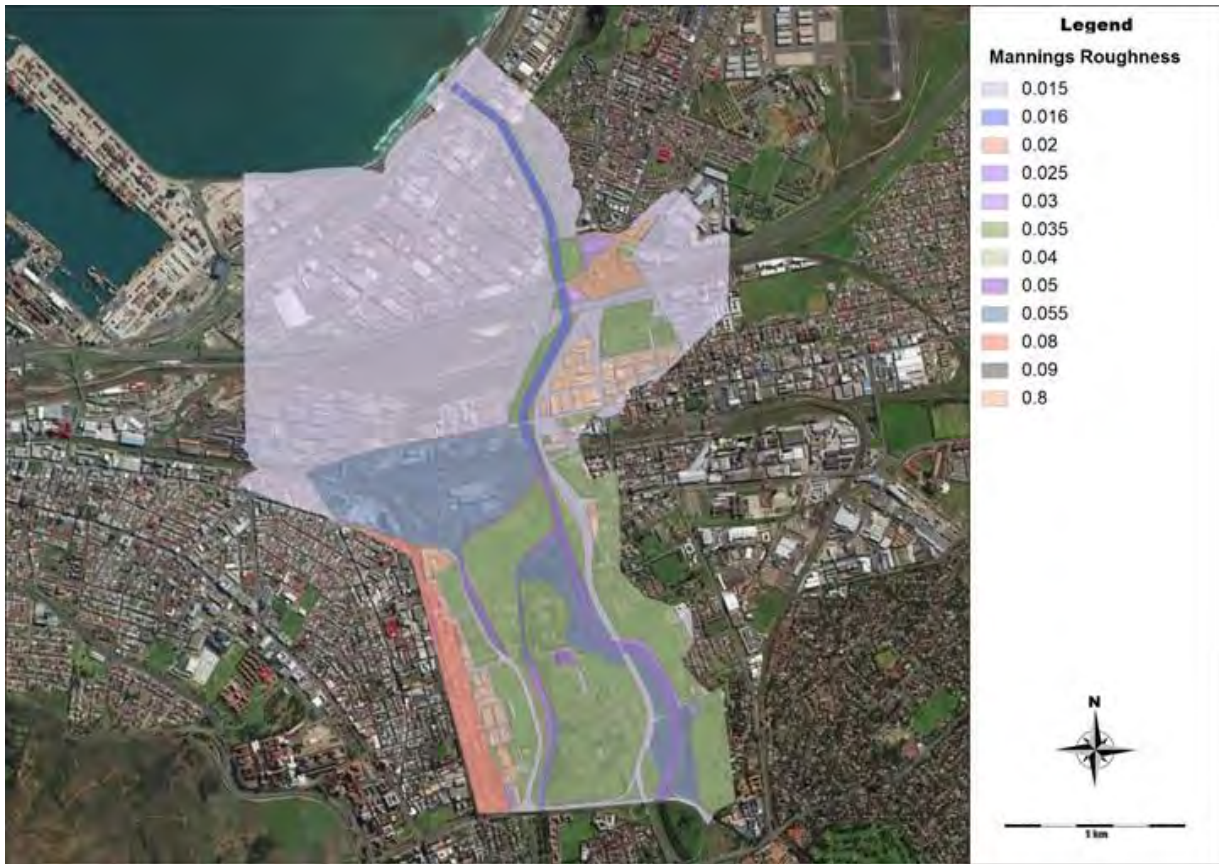


Figure 3-1 Manning's Roughness used for modelling

3.1.3 Digital Terrain Model (DTM)

To undertake 2D modelling – as required by the City – it was necessary to make use of an accurate Digital Terrain Model (DTM). This DTM was generated as follows:

- A 0.15 m DTM was created from the LiDAR ground points provided by the City.
 - These LiDAR points did not represent the river bed profiles (as LiDAR does not penetrate the water surface).
 - RH-DHV (2017) identified that a comparison between the various topographical surveys undertaken for the River Club and the original LiDAR data indicated that the LiDAR levels were generally lower than the corresponding ground surveys. Therefore, the levels of all the LiDAR points were raised by 0.25 m.
 - RH-DHV (2017) further noted that *“it was later confirmed by the City of Cape Town surveyor that a correction in the order of 0.25m was deemed necessary in other studies in the TRUP area as well.”*
 - Aurecon requested a topographical dataset from the City which had already been corrected. As this is the most recent topographical data, and appeared to best represent the site, it was used by Aurecon for all modelling.
- The underwater profiles of the river channels were generated as follows:
 - The 1D HEC-RAS Model created from a bathymetric survey undertaken as part of the RH-DHV (2017) study was provided by the City.

- RAS Mapper was used to interpolate and “export” 0.15 m DTMs of the various river channels.
- DTMs of the bridges were generated, based on the levels of the top of the railings (conservative assumption) surveyed for the RH-DHV (2017) study.
- These three DTMs were then merged to create a single representative DTM as indicated in Figure 3-2.

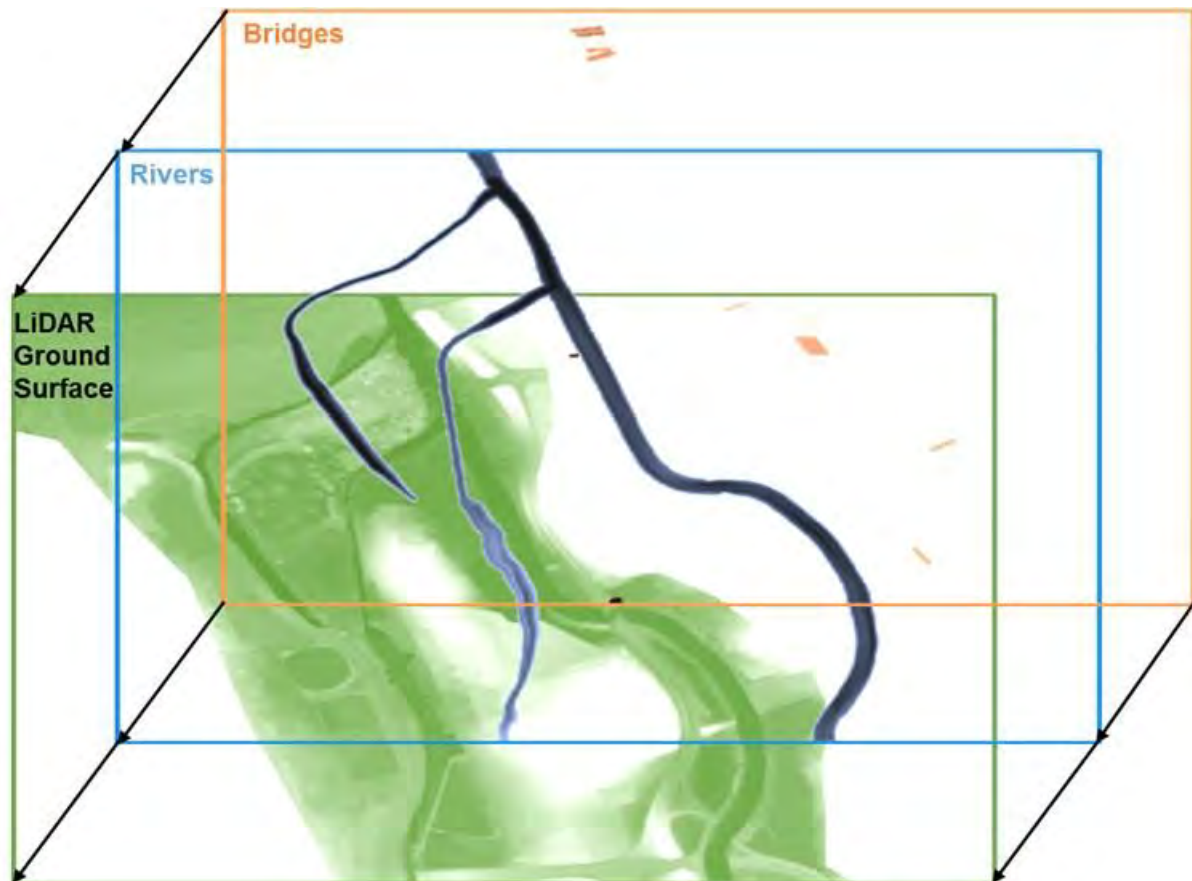


Figure 3-2 Merging of LiDAR, River and Bridge DTM's

3.1.4 Modelling of bridges / culverts

PCSWMM/PCSWMM2D does not contain a “Bridge modelling tool”. To ensure that the HEC_RAS model and the PCSWMM models could be compared, PCSWMM’s tool for importing hydraulic structures (e.g. bridges, culverts, weirs) from HEC-RAS was utilised. PCSWMM automatically converts bridges / culverts into a series of parallel conduits: one to convey bridge overtopping flow (high chord), and one or more to represent the opening(s) underneath the bridge deck. The high chord may be best represented by an irregular cross-section (transect), and each opening below the bridge deck by a custom cross section. The conversion from HEC-RAS to PCSWMM is illustrated in Figure 3-3.

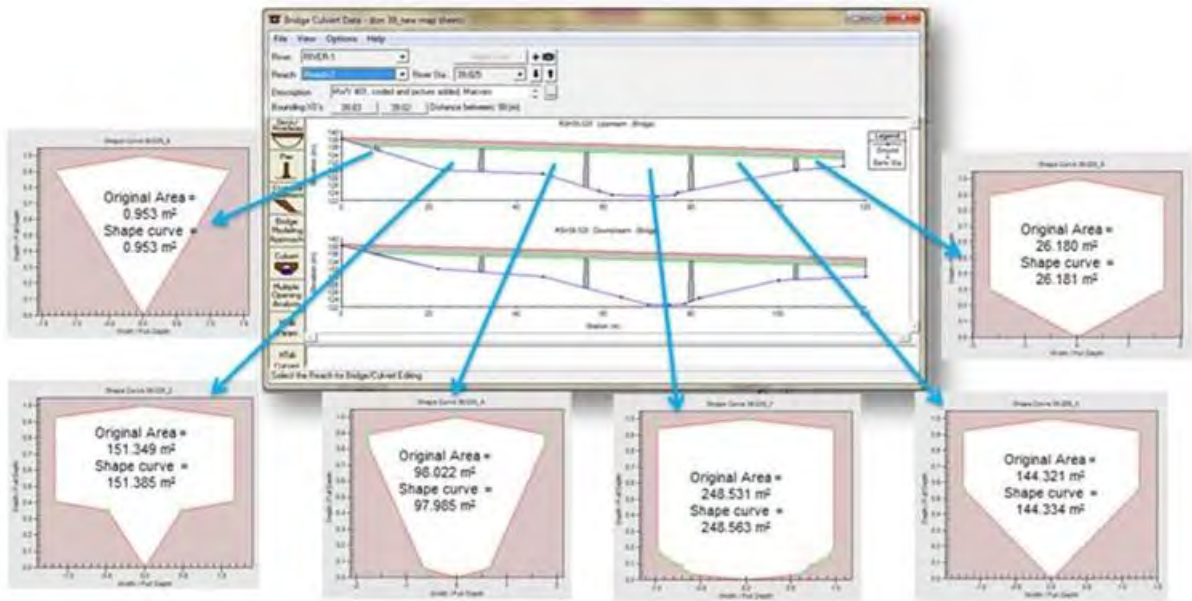


Figure 3-3 Importing of bridges from HEC-RAS into PCSWMM

For the PCSWMM model, energy loss coefficients were determined for bridges to account for the contraction and expansion of the flows under bridges (which are modelled by HEC-RAS in accordance with normal procedures). Loss coefficients were determined for the different bridges in accordance with James et al. (2012) to be as follows:

- Entrance Loss Coefficients (ELC) equivalent to the contraction coefficient used in HEC-RAS, and
- Average Loss Coefficient (ALC) equivalent to the expansion coefficients used in HEC-RAS.

The coefficients utilised for the SRK (2012) PCSWMM models were, typically, ELC 0.1, and ALC 0.3.

3.1.5 Boundary conditions

For both the PCSWMM2D and the HEC-RAS modelling the boundary conditions were as follows:

- The SRK (2012) hydrographs for the Black River and the Liesbeek Rivers were used as upstream boundary conditions.
- Within the modelling area, for the PCSWMM2D model only, the minor stormwater system was modelled.
- The boundary conditions at the outer edges of the floodplain assumed normal flow depth.
- The downstream boundary conditions for the Salt River Canal at the coast are shown Table 3-2. These conditions are based on the PRDW (2010) estimates which in turn were based on the SA Navy (2010). The peak tidal level was assumed to coincide with the peak flow in the Salt River which is a very conservative assumption as the tidal cycle is approximately 12.5 hours. PRDW (2010) also stated that *“It is also understood that the maximum flows expected in the Salt River Canal, and by implication the flood causing events, are expected approximately 12 hours after the maximum rainfall events in the catchment. This effect will further be complicated with varying local precipitation within the catchment.”*

Table 3-2 Tidal levels used in modelling

Recurrence Interval	High (mamsl)	Low (mamsl)	Explanation
100	2.53	0.9	PRDW (2010) 90th percentile tidal ranges and tidal levels – 50-year RI as used in RH-DHV (2017)
50	2.53	0.9	PRDW (2010) 90th percentile tidal ranges and tidal levels – 50-year RI as used in RH-DHV (2017)
20	2.45	0.83	PRDW (2010) – 20-year RI as used in RH-DHV (2017)
10	1.99	0.5	Current MHWS/MLWS allowing for: <ul style="list-style-type: none"> • 0.45m storm surge • 0.55m for sea level rise as a result of climate change
<5	1.76	0.27	Current MHWS/MLWS allowing for: <ul style="list-style-type: none"> • 0.25m storm surge • 0.55m for sea level rise as a result of climate change

Note: These are the Still Water Levels excluding individual wave crest and excluding wave run up. These latter processes are not relevant here since the levels here are used for the downstream water level boundary in the SWWM model which will not resolve individual wind-waves.

It is important to recognise that a 1 in 100-year recurrence rainfall (which is assumed to cause the 1 in 100-year flood) and a 1 in 100-year tidal event do not necessarily coincide. In principle, the probability of each occurring separately is 1% and occurring simultaneously is 0.01% or equivalent to a 1 in 10 000-year event. However, there is likely to be some relationship between storm events at sea, and flood events on land – but not necessarily of equal magnitude and recurrence interval.

PRDW (2010) investigated the correlation of storm surge and rainfall events using 24 years of data at the South African Weather Service’s Observatory rainfall station. Their investigation found that *“Preliminary results show limited correlation of extreme rainfall and storm surge. The maximum rainfall from the correlated data set (~90 mm representing a return period between 1:20 and 1:50 years) occurred with small positive storm surge (~0.1 m representing a return period less than 1:10). While the maximum storm surge from the correlated data set (~0.75 m for a return period > 1:100) occurred with a relatively small rainfall (~30 mm for a return period < 1:10).”*

PRDW (2010) concluded that *“based on the level of uncertainty of the response of the catchment hydrograph to precipitation events, specifically with respect to the time delay in peak flow, it is recommended that the calculations for return period floods are calculated with the equivalent return periods for rainfall (i.e. 1:100-year flood and 1:100-year rainfall) and a lower return period for storm surge for the sea interface (i.e. 1:10 year storm surge for example).”*

As noted by PRDW (2010) the correlation between storm surge and rainfall is complicated due to a range of factors including timing, rainfall distribution across the Salt River Catchment and tidal cycle (Spring high or Spring low). Therefore, a simple analysis was undertaken using 10 years of rainfall data at the Newlands rainfall station which provides an indication of high rainfalls in the Liesbeek River Catchment as a result of the orographic effect caused by Table Mountain. This analysis indicated that approximately 30% of rainfall events occurred on a day when the peak sea level exceeded the Mean High-Water Spring (MHWS) tidal level. An analysis of the 10 largest rainfall events with precipitation of between 90 mm and 130 mm (per day), roughly equivalent to 1-5-year Recurrence Interval events, indicated that 4 of the 10 events occurred when tidal levels exceeded the MHWS level.

Based on the above findings, particularly those of PRDW (2010), it is considered that the assumptions used for the RH-DHV (2017) study are reasonable and have been adopted for the analyses described below.

3.1.6 Accounting for intra year events

The City has developed standard design storms and hydrological models for 1 in 2-year, 5-year, 10-year, 20-year, 50-year, and 100-year recurrence interval events. These storm rainfalls and flood discharges were analysed and both were found to have linear relationships when plotted with a log normal distribution. Using this relationship, it was possible to estimate the flows at the boundary of the modelling area, as well as the precipitation parameters for the 0.5-year and 1-year storm events.

Providing the parameters for a 1-year or smaller storm event is, statistically speaking, not possible as it implies that every year, without fail, an event of that magnitude or greater will take place. As was evident in 2017, it is possible that such an event does not take place. However, for the purposes of this analysis it was felt that such an approach was reasonable and would provide the required insights.

3.2 Development Layouts

The layouts for the proposed development have evolved through a number of iterations with the proposals increasingly gaining a focus towards transforming the Liesbeek River Canal into a more natural river channel that provides habitat for a variety of fauna and flora. This would link with the Raapenberg wetlands and is seen as improving the overall functioning of the ecological systems in the area. The changes have resulted in two primary development options:

- Option 1 (Figure 3-4) – which envisions the transformation of the Liesbeek canal and the partial filling of the ‘old’ Liesbeek River; and
- Option 2 (Figure 3-5) – which leaves the Liesbeek canal and ‘old’ Liesbeek River largely untouched.

On account of the backwater effects of the downstream railway bridges – essentially causing a damming effect that impacts on the River Club site – the differences between Options 1 and 2 are inconsequential. Therefore, this study has been based on the Option 1 layout which is also perceived to be the preferred layout.

It should be noted that the proposed development is not explicitly in accordance with the City’s ‘Floodplain and River Corridor Management Policy’ (CSRM, 2009a) and would require the City to make exceptions for the following provisions:

- Section 9.2: Flood Management and Public Safety
 - Permission to develop / obstruct the free flow of water within the 20-year flood line area would need to be granted.
- Section 10.5: Table 1: Framework for the assessment of Proposals
 - The current assessment framework forbids development (including filling) within the 50-year flood plain. It notes: *“In exceptional circumstances minor “smoothing” of the 50 / 100-year flood line may be considered, provided equivalent compensatory stage storage volume is provided within the development precinct”*.
 - As the proposed development falls under the 50-year flood line, a deviation from the policy, allowing the developer to fill (considered development) would need to be granted.

Notwithstanding the above, the City could approve the development based on the “*geomorphological, maintenance, social and economic aspects*” (presented by other specialists), and on the findings of this study.

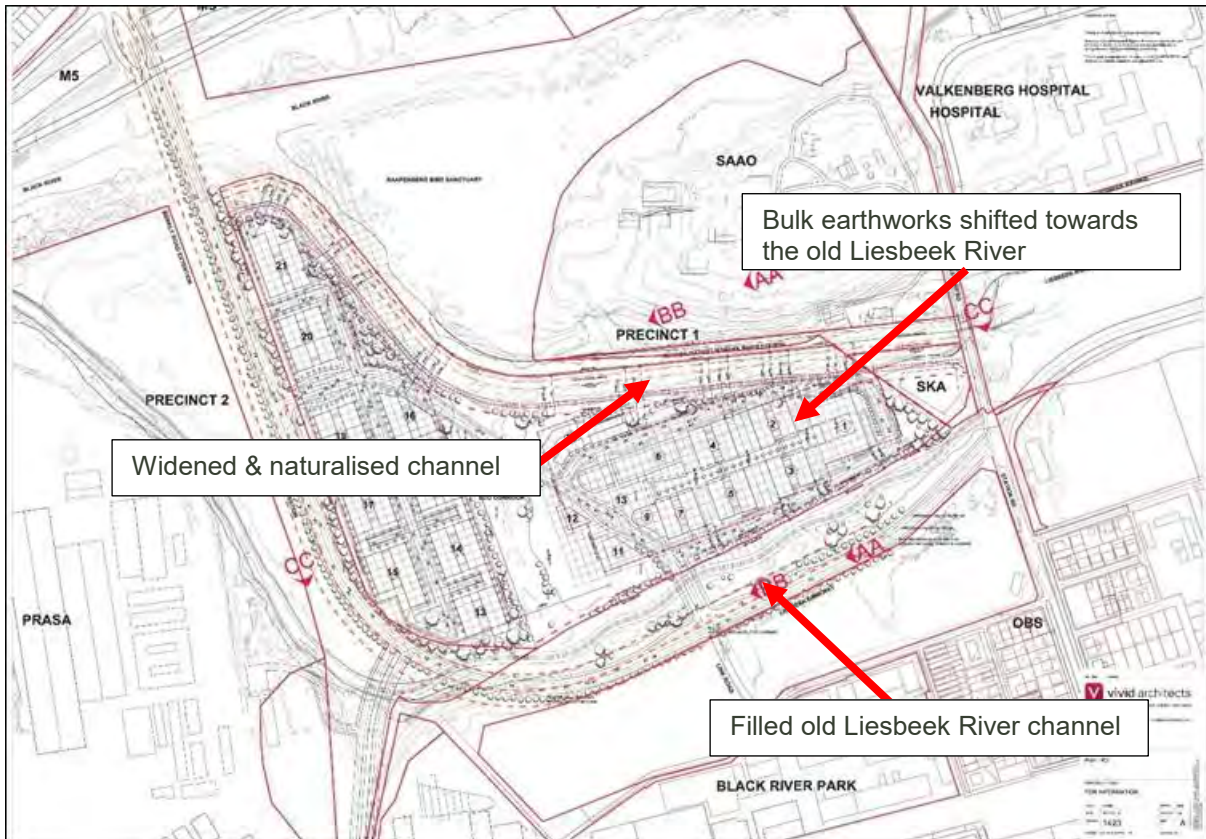


Figure 3-4 Layout option 1, showing the most significant difference with Option 2

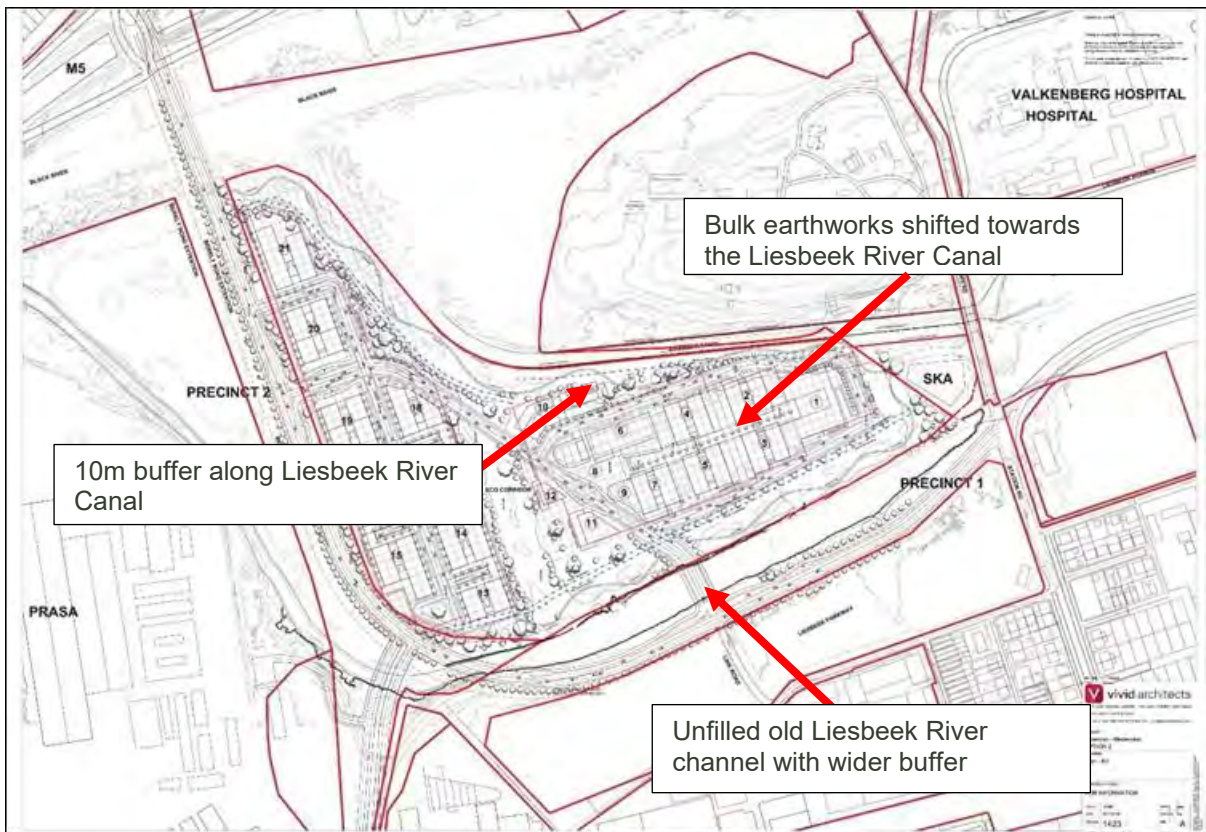


Figure 3-5 Layout option 2, showing the most significant difference with Option 1

3.3 PCSWMM-2D

PCSWMM-2D was used as the primary tool for analysing the impact of the proposed River Club development on the surrounding areas. PCSWMM was selected because:

- The City had recently used PCSWMM for a similar study of the area and therefore the use of PCSWMM for the current study would facilitate comparisons;
- PCSWMM incorporates the minor stormwater system into the model – which is important within an urban area; and
- The background models – previous studies prepared for the City – were SWMM based.

For the current study the PCSWMM models were set up as 1D-2D models. This models the minor stormwater system and the river channel as 1D conduits and the floodplain as a 2D mesh. The selection of the mesh resolution was important as higher resolution meshes result in longer model run times, whereas lower resolution meshes might affect the reliability of the results. The selected mesh resolution used within the modelling area is shown in Figure 3-6. As is evident from Figure 3-6, the mesh in the vicinity of the River Club was generated with a significantly higher resolution than the mesh for areas of less interest – e.g. Paarden Eiland.

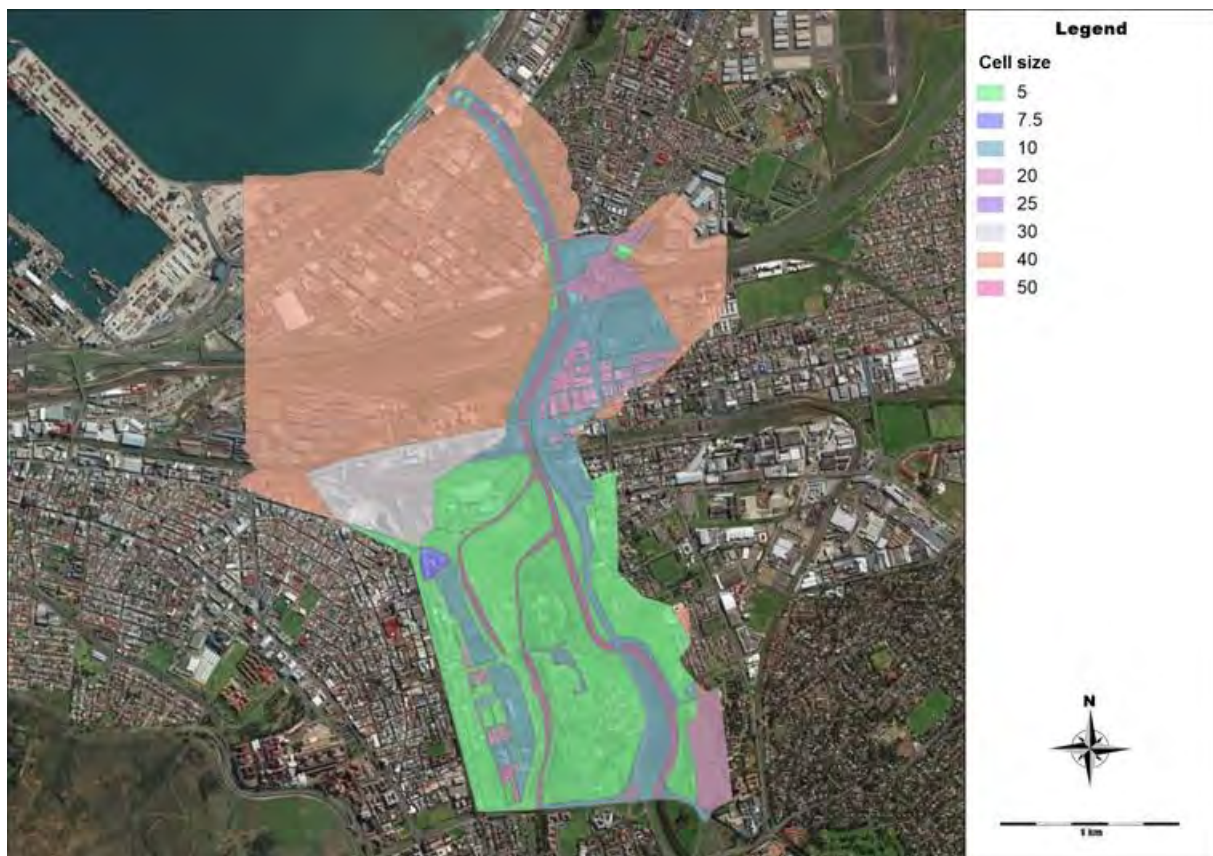


Figure 3-6 Area modelled in 2D showing the resolution of mesh in each area

3.4 HEC-RAS

HEC-RAS 5.0.3 was used in this study to model the site in 2D. This was in response to comments made in RH-DHV (2017) which questioned the use and appropriateness of PCSWMM. Both PCSWMM and HEC-RAS have their own strengths and weaknesses for modelling and therefore it was decided to undertake the additional HEC-RAS modelling as a confirmatory check – not to replace the PCSWMM model.

The 2D mesh for the HEC-RAS model was developed using QGIS and the 'RiverGIS' plugin. For the HECRAS mesh (Figure 3-7), the same break lines that were used for the PCSWMM model were used and supplemented by break lines along the centres and edges of the respective rivers. The addition of the break lines representing the centres and edges of the respective rivers in the HEC-RAS model was utilised due to the HEC-RAS model being a fully 2D model, and because of HEC-RAS's computational methods. It was also necessary to ensure that the edges of the river (sometimes elevated above the surrounding area) were clearly defined to prevent 'leakage' within the modelling.

HEC-RAS is currently unable to model bridges in the fully 2D modelling environment, and as noted in Neelz & Pender (2013) there is a degree of uncertainty concerning the linking of 1D channels and the 2D flood plain. Therefore, it was decided to use HEC-RAS in a fully 2D modelling environment (rather than the 1D-2D modelling environment) and to overcome the existing restriction with regard to modelling of the bridges within the 2D environment, two approaches were followed:

- Both approaches make use of open source software, and therefore once the 2D mesh was generated it was imported into HEC-RAS where the Mesh was edited, finalised and the relevant 2D modelling parameters were generated.
- HEC-RAS made use of the same DTM's and land-use / roughness parameters as SWMM.



Figure 3-7 HEC-RAS 2D Mesh – showing varying resolutions

3.5 Accuracy of Models

The City has, historically, preferred two models for hydraulic and hydrological modelling. The hydrological determinations have typically been undertaken with PCSWMM, and the hydraulic modelling with HEC-RAS. It is worth noting that the PCSWMM routes the runoff from multiple sub catchments by performing hydraulic calculations, and therefore that it is not purely a hydrological model. PCSWMM's routing can therefore have an impact on the HEC-RAS outputs. More recently the City has preferred PCSWMM 2D for its 2D modelling. It should be noted that modelling hydraulic and hydrological systems is not an exact deterministic science – different models and modellers may obtain different results. This is further complicated by the selection of modelling approach. PCSWMM 2D Modelling approach – sometimes called ‘quasi-2D – is equivalent to the ‘diffuse wave solution’ in that it does not incorporate the full 2D momentum equation. On the other hand, HEC-RAS uses the ‘diffuse wave solution’ – as opposed to the ‘full momentum solution’ – which runs faster and is more stable. While the full momentum solution is considered more accurate it does require calibration – as do all models – and HECRAS also contains more parameters for which values are uncertain – especially when calibration is not possible.

The variation in modelling results is evident in the recent 2D bench marking studies – based on the original benchmarking study by Neelz & Pender (2013) – where the results varied for a variety of reasons between the different models as shown in Figure 3-8. It is worth noting that when PCSWMM modelled the scenario the results (overlaid on top of the original study) appeared to be reasonable. HEC-RAS also modelled the same scenario and its results were also reasonable. There were differences between the full momentum and diffuse wave solutions of about 300mm – as shown in Figure 3-9.

Essentially, a review of both the PCSWMM and the HEC-RAS models indicated that both provide reasonable 2D modelling results.

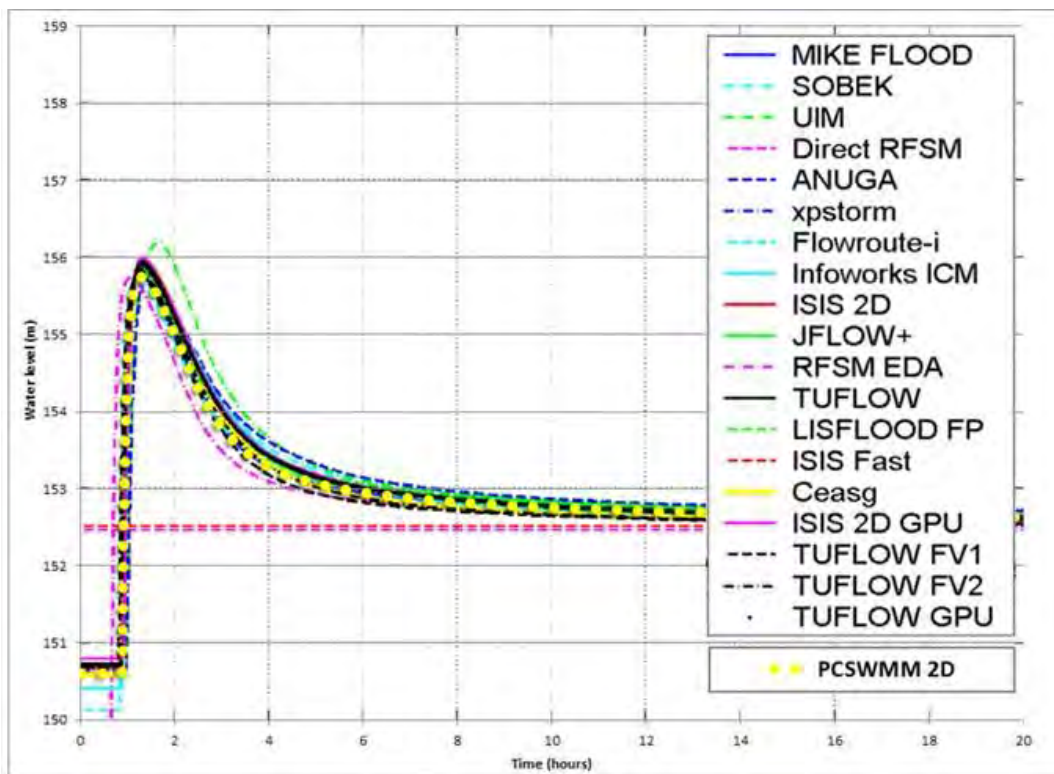


Figure 3-8 Comparison of the 2D modelling results for a valley flooding scenario (Test 5 , Point 3) (Neelz & Pender, 2013)

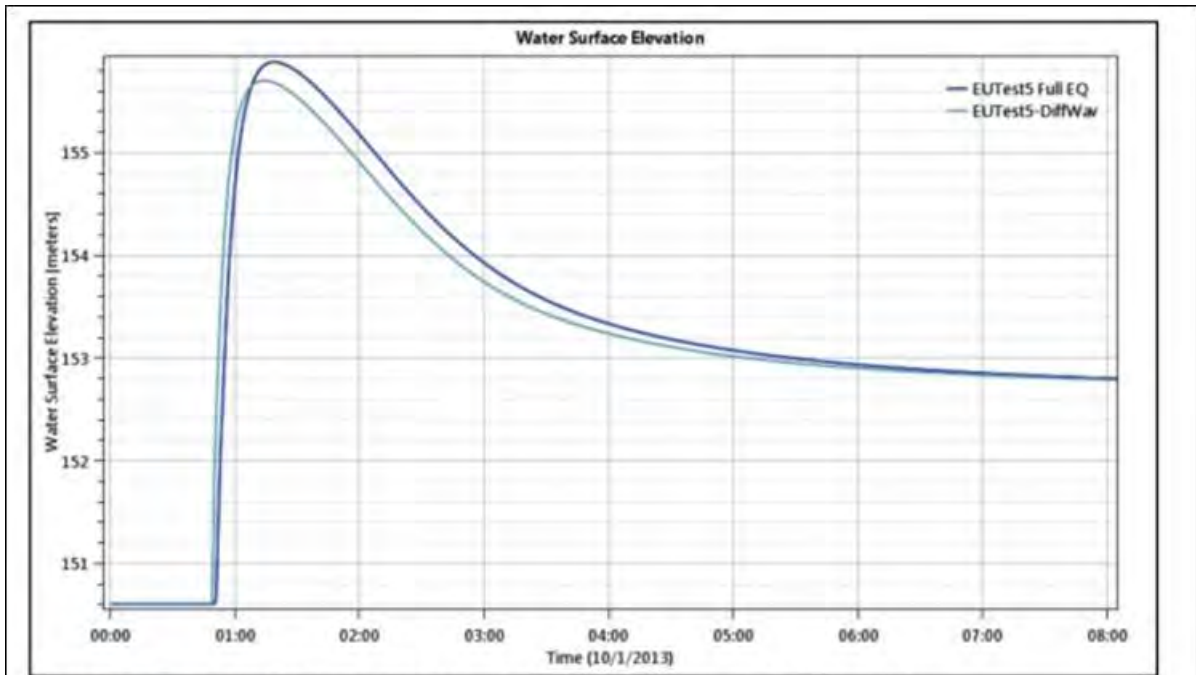


Figure 50. Test Point 3 - Water Level (depth) for Full Equations and Diffusion Wave.

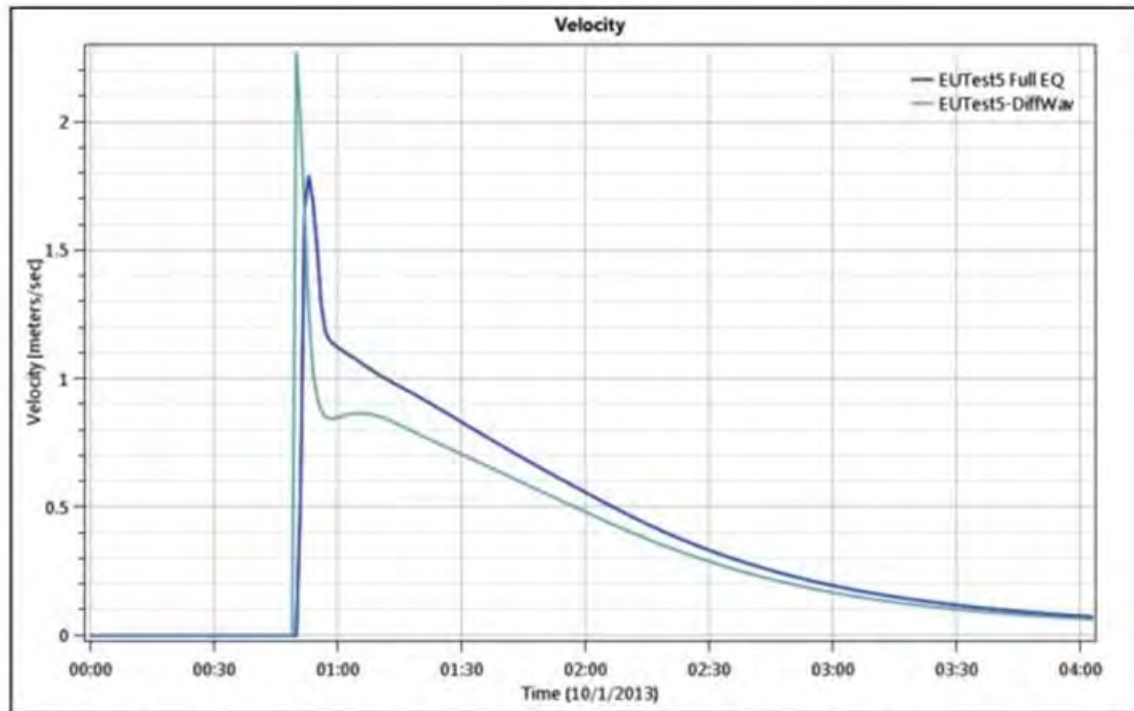


Figure 51. Test Point 3 - Velocity Time Series for Full Equations and Diffusion Wave.

Figure 3-9 Comparison of the 2D modelling results for a valley flooding scenario (Test 5 , Point 3) (Brunner, 2016)

3.5.1 Model complexity

It is important to recognise the context, especially with regard to data availability, within which these models have been developed. Wainwright & Mulligan (2013) state that an *'optimal model is one that contains sufficient complexity to explain phenomena, but no more'*. James (2005) suggests that it is sometimes assumed that the reliability of a model will increase with its complexity to a certain point, and that beyond this, the reliability will decrease (Figure 3-10). James (2005) notes that this has never been proven for surface water models. Therefore taking a parsimonious approach to modelling – developing a model with the greatest explanatory power and the fewest parameters or complexity – *is a particularly important principle in modelling since our ability to model complexity is much greater than our ability to provide the data to parameterize, calibrate and validate those same models'*(Wainwright & Mulligan, 2013).

It is difficult to determine the required level of complexity, as there is no accepted measure of this (James, 2005). However, experience and intuition will assist in the development of good models (Wainwright & Mulligan, 2013).

Data are crucial for the development and calibration of reliable models. In theory, the more data available, the more reliable the model should be (James, 2005). There is a relationship between complexity and the amount of data that is available as shown in Figure 3-11 which suggests that a more complex model will be more uncertain than a less complex model with minimal data, but less uncertain than a less-complex model with a lot of data.

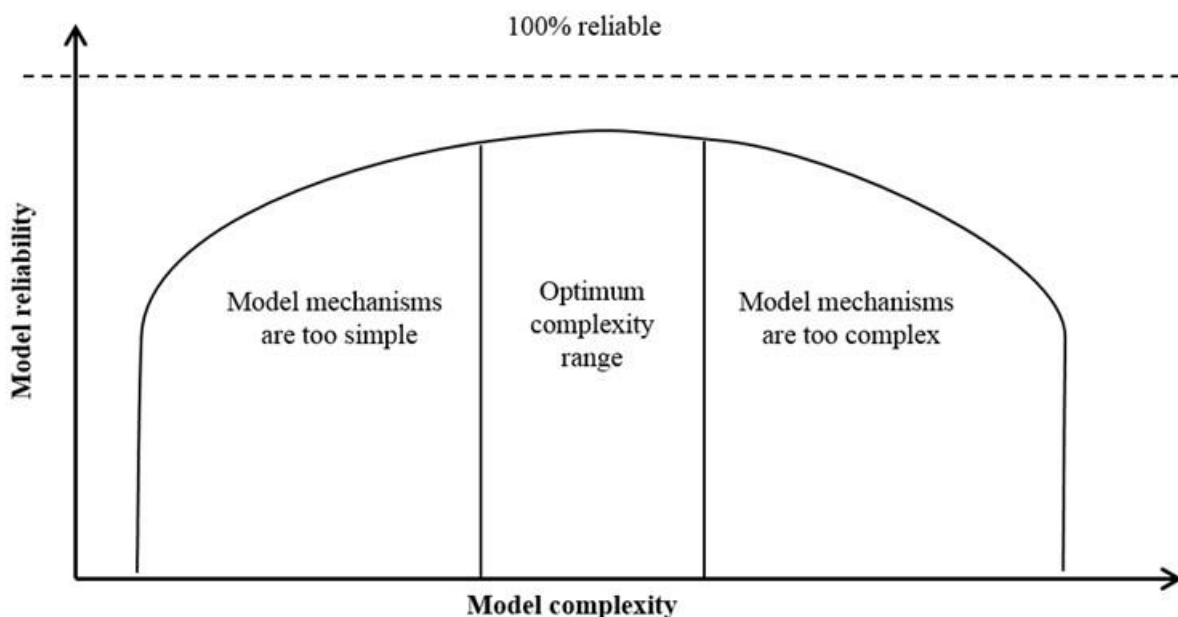


Figure 3-10: Relationship between complexity and reliability (After James, 2005)

In essence, choosing the correct level of complexity is a difficult but important part of modelling. Models should be neither overly complex nor too simple. Overly complex models will consume more time and money and potentially offer less reliable results. On the other hand, a model that is too simplistic may not offer adequate reliability (Wainwright & Mulligan, 2013; James, 2005; van Waveren et al., 1999). Ideally it is preferable to select *'no more complex a model or representation of reality than is absolutely necessary'* (Wainwright & Mulligan, 2013).

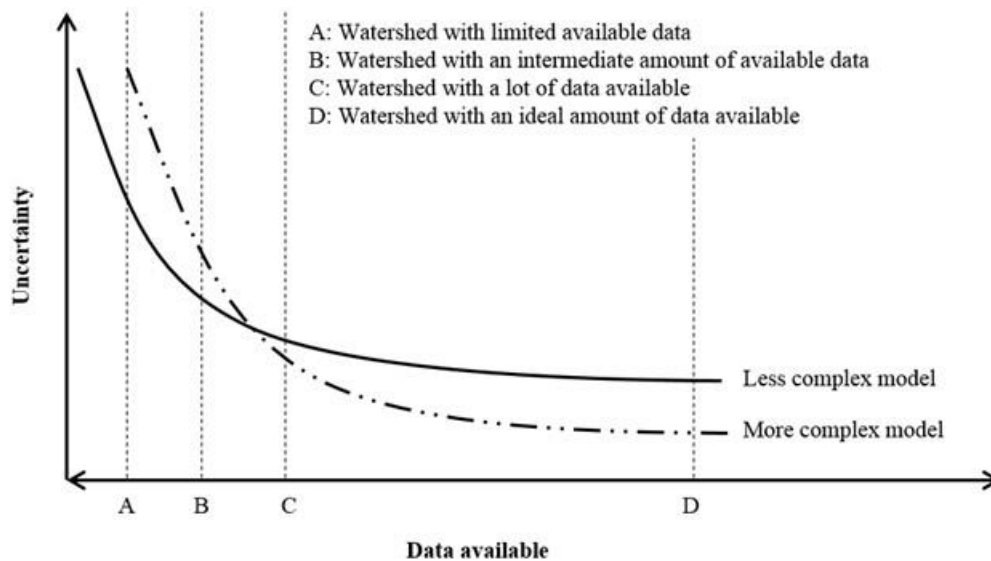


Figure 3-11: Relationship between data, uncertainty and complexity (After James, 2005)

Considering that this catchment has limited functional and reliable flow or depth gauges, it is not reasonable to expect a very complex model (i.e. full momentum 2D model) to be of much additional value as there is too much uncertainty – especially concerning the modelling of bridges.

3.5.2 Advantages and disadvantages of the different models

Both HEC-RAS and PCSWMM provide reasonable results. Each model has its own advantages and disadvantages as follows:

- HEC-RAS is generally better for modelling large river systems:
 - HEC-RAS 1D is better at modelling bridges and inline structure
 - HEC-RAS 1D provides a more accurate Energy Grade Line (see Section 3.7)
 - HEC-RAS 2D is currently not capable of modelling bridges and instead assumptions – much as for SWMM – need to be made.
 - HEC-RAS 2D can implement the full momentum 2D modelling equations, but without calibration this adds further uncertain parameters which may affect the results.
- PCSWMM is generally better for modelling in urban areas:
 - Models the stormwater system – both major and minor – which allows it to highlight potential trapped low points and back flooding through the stormwater system
 - Does not discretely model bridges, but approaches have been developed and tested that account for the energy losses at the bridges in the SWMM model (e.g. James et al., 2012).
 - SWMM 2D – a ‘quasi’ 2D model – allows for the incorporation of the minor stormwater system with surface flows.

While the Black River is a ‘large river’ for Cape Town, it is not particularly large when compared to other rivers in South Africa and across the world. The surrounding urban areas are relatively low lying and thus being able to incorporate the minor stormwater systems in the modelling is important and useful as there is evidence that some of the flooding is due to the minor systems surcharging. Therefore, while

both HEC-RAS and PCSWMM could be used, it is considered that because of the urban nature and various types of flooding (e.g. surcharging of minor systems) PCSWMM is likely to provide the best representation of the flooding for the various flood recurrence intervals. On the other hand, HEC-RAS was used to confirm that the PCSWMM results were reasonable.

3.6 Quantifying the Risk to the Raapenberg Wetlands


Dr Day – the appointed Fresh Water Ecologist – identified the need to quantify the risk of changes to the hydrological and hydraulic regime in the Raapenberg wetlands as a critical component of her study. Initially, this was to be achieved by utilising flow data collected by the City. Of the two gauging stations, only the downstream station (Glamis Close) was in operation. After an analysis, and cleaning of the data it was determined that the data was not reliable. This meant that any analysis undertaken by Dr Day would have a low level of confidence, and so would not be of use in assessing the impact on the Raapenberg Wetlands. It was therefore decided that it would be necessary to approach this aspect of the surface water study differently. This was done by surveying the Raapenberg wetlands, and using biological indicators (e.g. reed and other plant zonation) to deduce what were the critical potential hydrological and hydraulic impacts. The survey identified a number of important features of the area:

- The water level in the Raapenberg wetlands is approximately 250mm lower than that in the surrounding Rivers.
- There is evidence of wetland vegetation that grows in brackish water.
- There was an informal intervention shown in Figure 3-12 which was to excavate with the intention of increasing / allowing flows into the wetland. This intervention was performed by a “Friends of the Liesbeek” maintenance team following concerns raised by SAAO and members of TRUPA regarding the lack of water in the Raapenberg wetland. The intention was to try and divert water into the wetland.
- There is an artificial channel that seems to have been created along the boundary of the SAAO property. This is not linked to the Liesbeek or Black River Systems.



Figure 3-12 Intervention that encourages flows into the wetlands

The findings of the site visit suggested:

- 
- An increase in the recurrence interval of flooding would have a negative effect on the functioning of the wetland. Therefore, the pre- and post (proposed) development scenarios were modelled to determine when the wetland would fill with water.
 - The increase in volume flowing into the wetland would have a negative impact on the functioning of the wetland as the wetland is not primarily a freshwater system, and because increased water depths would result in a change in the distribution of different plant species (Flow into the wetland cannot drain out due to the differential in the water levels in the wetland and in the nearby rivers). As such the pre- and post (proposed) development scenarios were modelled to determine when the wetland would fill with water.

3.7 Widening the Salt River Channel

In 2004 Ninham Shand undertook a study on behalf of City which investigated the possible widening of the Salt River Canal. This emanated from a review of a 1957 Council proposal for flood relief which involved widening, and in some areas, concrete lining of the river channel. This scheme would entail the widening of the Salt River Canal from the original current width of 46 m to 61 m (an increase of 15 m). In 1974, the City's Executive Committee approved a recommendation by the Utilities and Works Committee that the Salt River Canal (canal downstream of the Railway Bridges) be widened (by 15m) and that land adjacent to the canal, that was required to effect the widening, be acquired by the City. To date, some of the required land is still not owned by the City and the widening of the canal has not been implemented.

In the 2004 Ninham Shand study, and in line with the 1974 scheme approved by the Executive Committee, all existing road and rail bridges over the Salt River Canal were evaluated in terms of requirements for widening of the canal.

The results indicated some significant changes in the elevation of the flood line. When these elevations are plotted on the latest DTM, the benefits of this scheme are only realised in the vicinity of the PRASA site – Figure 3-13. It is important to note that the Ninham Shand report of 2004 was produced prior to the adoption of climate change and sea level rise factors.

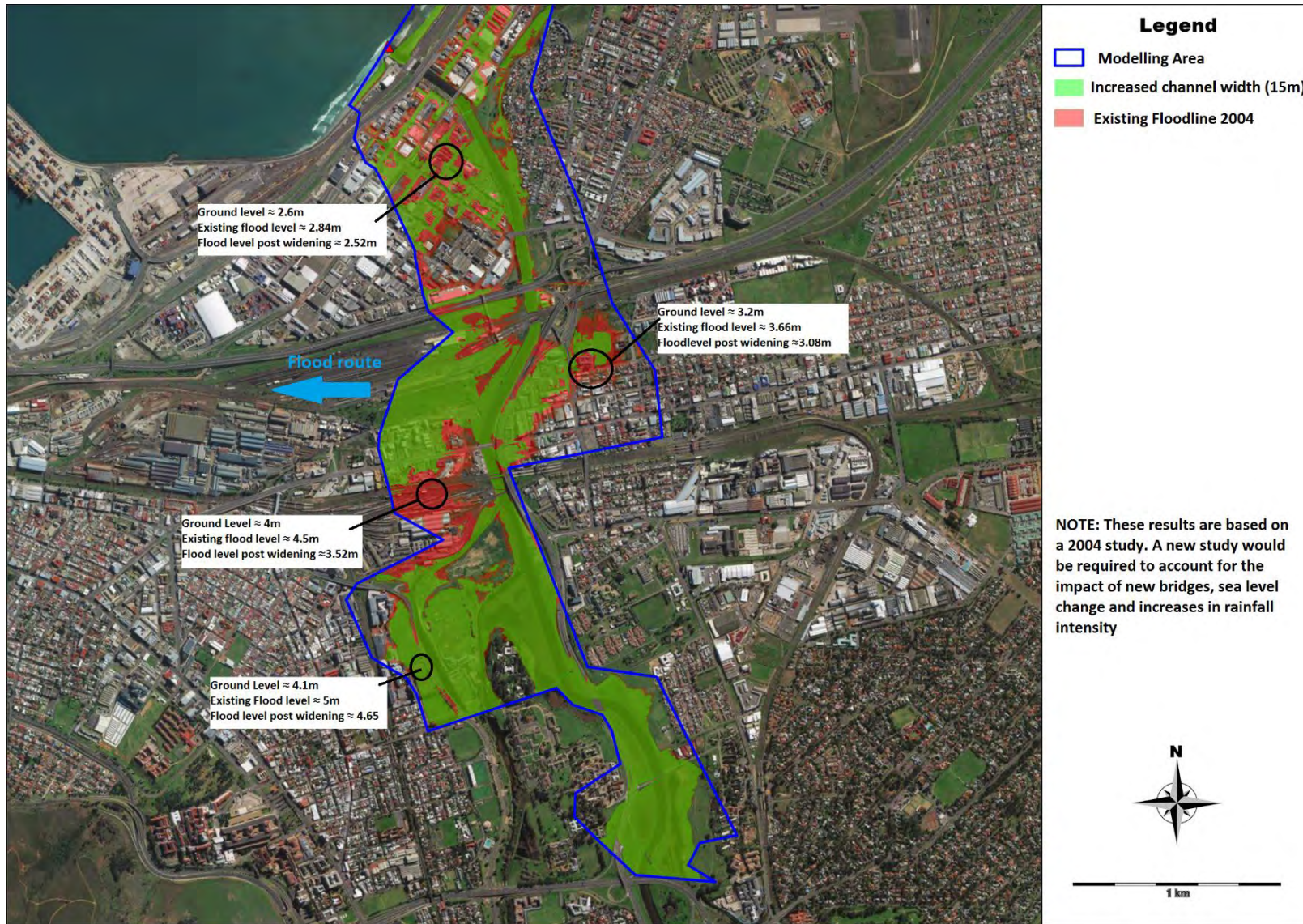


Figure 3-13 The effect of widening the Salt River Canal and associated bridges based on Ninham Shand 2004

The TRUP study (RH-DHV, 2017) also considered widening of the Salt River Canal. The study examined the potential benefit of widening the canal by modelling an additional 25 m wide rectangular canal in parallel with the Black River channel and the existing Salt River Canal, together with widening of the bridges crossings. It is uncertain why 25m was selected, and it is unlikely that it would be possible to widen more than the 15m originally proposed. RH-DHV found that immediately downstream of the N2, there would be a predicted reduction of 0.83 m in the water level due to the 15 m widening. The RH-DHV report noted that canal enlargement would involve significant capital costs.

The City, none the less requested that this study also consider the possible effect of widening the canal and removing any restrictions (e.g. bridges). The following assumptions were made:

- The bridges could be engineered / re-engineered to not affect the flow in the Salt River – i.e. span the river.
- The canal was assumed to be a 61m rectangular cross-section – with the same invert levels as the existing canal.

Such a scenario would represent the ‘absolute best case’ scenario and is, in Aurecon’s view, unlikely to ever be realised. The City, however requested, that no option / possibility should be excluded.

3.8 Sediment build up at the canal outfall

It was noted that the survey showed that sediment had built-up at the Salt River Canal outfall into the ocean. A review of historic images – on Google Earth – indicated that since 2000 there was only one year (Figure 3-14) in which the canal was clear – i.e. no sediment build up – meaning it had 100% of its capacity. Aurecon believes that during any significant flood this sediment would erode effectively leaving the canal with its full capacity. This may not happen for smaller floods. Therefore, all recurrence intervals were modelled assuming the sediment would not erode (worst case scenario), except the 100-year event which was modelled twice assuming that the sediment would / would not erode.



Figure 3-14 Evidence of sediment at the mouth of the Salt River for 16 of the last 17 years.

3.9 Closing the ‘PRASA’ overland escape

As highlighted in Section 2.2, all the previous studies have identified a major storm event flood route across the PRASA site. There has been concern about what would happen if this flood route were to be closed. While doing so would be illegal and counter to the City’s policies, the City nonetheless requested that this scenario be modelled. In order to do so it was assumed that PRASA would berm the ‘old’

Liesbeek so that flood waters would not flow onto its property. This scenario was tested for both the status quo and the post development scenarios.

3.10 Water Surface vs Energy Level

It is important to note that all results in this report, and all conclusions drawn from the reported results are based on simulated Water Surface Elevations (WS) and not on Energy Levels (EL). This is contrary to the City's 'Floodplain and River Corridor Management Policy' (CSRM, 2009a) (developed prior to the widespread use of 2D modelling) which requires that "all flood lines must be based on the theoretical energy level as opposed to the water surface level". These requirements are most appropriate for 1D models, whereas on this site the City has indicated a preference for 2D modelling. The use of energy levels is not appropriate for 2D modelling as for 2D models the extent of flooding is determined by the boundary between "wet" and "dry" cells. At the edge of the flood extent flow velocities are typically minimal / non-existent and therefore the Energy Level is, approximately, the same as the Water Surface level.

Where the energy level has been provided, this has been done by adding the energy head ($V^2/2g$) to the water level.

3.11 Hazard Analysis

The City's 'Floodplain and River Corridor Management Policy' (CSRM, 2009a) considers, as part of its flood plain management, the hazard that flooding may pose to life and property. The hazard posed by flood waters (excluding water quality) is based on the ability to wade or gain vehicular access as well as the stability of structures such as dwellings or boundary walls. If these are likely to be seriously compromised, the area is considered to be in the High Hazard Zone. In terms of the City's 'Floodplain and River Corridor Management Policy' "No new or additional rights or the exercising of existing development rights will be granted to properties located within the high hazard zone" as determined in accordance with Figure 3-15 (CSRM, 2009a) .

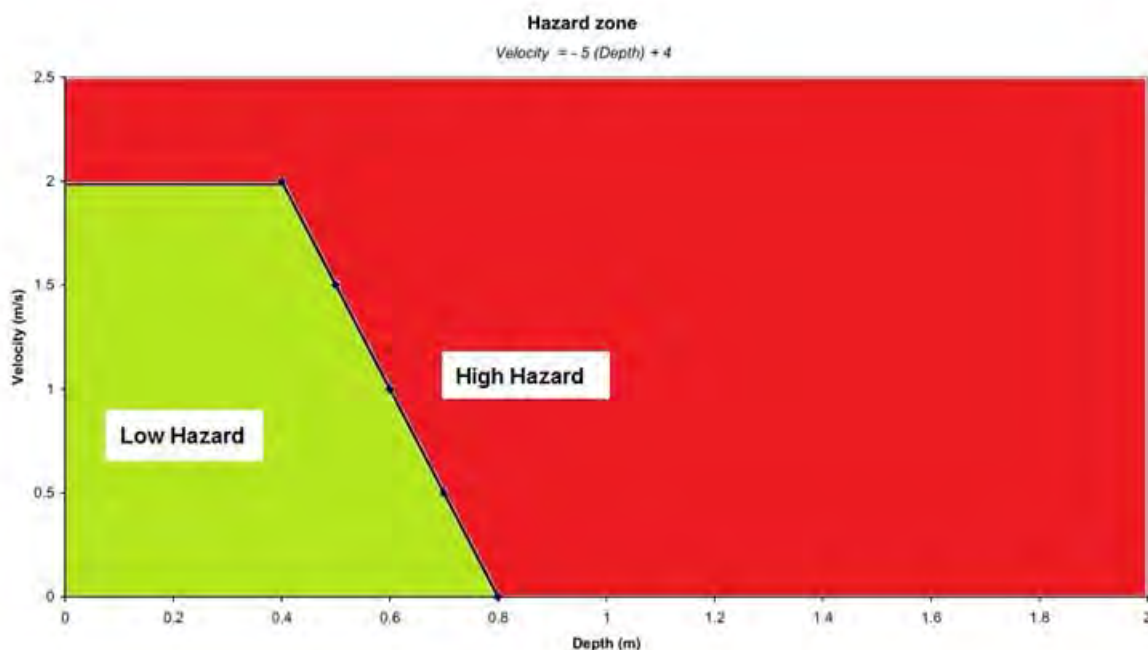




Figure 3-15 Flood Hazard Zones

Furthermore, the City's 'Floodplain and River Corridor Management Policy' (CSRM, 2009a) notes that: *"The permissible extent and nature of land use, development or activities within floodplains must be subject to stringent evaluation and control in the interests of public safety. In particular, obstruction to the free flow of water within the 20-year flood line area shall not be permitted. However, between the 50 and 100-year flood lines, some developments or activities may be permitted, subject to such conditions as the City may in its discretion impose, while developments with particular evacuation or emergency response issues and high risk developments will only be permitted above the 100-year flood line"*

3.12 Sensitivity Analysis

In order to ensure that any queries relating to the accuracy / reliability of the City's hydrologic models for the greater Salt River catchment could be quantified, a sensitivity analysis was undertaken by modelling a storm with a 1 in 200-year Recurrence Interval using the same approach as discussed in Section 3.1.6 for the scaling of intra-year events.

4 Modelling Results

This study assessed 35 Scenario's with a total of 39 model runs utilising two 2-Dimensional hydraulic modelling software packages (PCSWMM and HEC-RAS) as summarised in Table 4-1 – making it the most comprehensive study of the site to date. It is not possible to present all output data in this report, and therefore only relevant information from the over 900GB of output data which was generated is presented.

Table 4-1 Overview of the scenarios that were modelled and the model runs undertaken as part of this study.

Scenario	PCSWMM	HEC-RAS
Status Quo: 0.5-year	✓	✓
Status Quo: 1-year	✓	✓
Status Quo: 2-year	✓	
Status Quo: 5-year	✓	
Status Quo: 10-year	✓	
Status Quo: 20-year	✓	
Status Quo: 50-year	✓	
Status Quo: 100-year	✓	✓
Status Quo: 100-year (with widened Salt River canal)	✓	
Status Quo: 100-year (with 10-year sea level)	✓	
Status Quo: 100-year (PRASA overland route closed)	✓	
Status Quo: 100-year (PRASA overland route closed, Bridges obstructed)	✓	
Status Quo: 200-year	✓	
Post-development (River Club only): 0.5-year	✓	
Post-development (River Club only): 1-year	✓	
Post-development (River Club only): 2-year	✓	
Post-development (River Club only): 5-year	✓	
Post-development (River Club only): 10-year	✓	
Post-development (River Club only): 20-year	✓	
Post-development (River Club only): 50-year	✓	
Post-development (River Club only): 100-year	✓	
Post-development (River Club only): 200-year	✓	
Post-development (River Club, TRUP, NRF, PRASA): 0.5-year	✓	✓
Post-development (River Club, TRUP, NRF, PRASA): 1-year	✓	✓
Post-development (River Club, TRUP, NRF, PRASA): 2-year	✓	
Post-development (River Club, TRUP, NRF, PRASA): 5-year	✓	
Post-development (River Club, TRUP, NRF, PRASA): 10-year	✓	
Post-development (River Club, TRUP, NRF, PRASA): 20-year	✓	
Post-development (River Club, TRUP, NRF, PRASA): 50-year	✓	
Post-development (River Club, TRUP, NRF, PRASA): 100-year	✓	✓
Post-development (River Club, TRUP, NRF, PRASA): 100-year (with widened Salt River canal)	✓	
Post-development (River Club, TRUP, NRF, PRASA): 100-year (with PRASA overland route closed)	✓	
Post-development (River Club, TRUP, NRF, PRASA): 100-year (with PRASA overland route closed and bridges obstructed)	✓	
Post-development (River Club, TRUP, NRF, PRASA): 100-year (with 10-year sea level)	✓	
Post-development (River Club, TRUP, NRF, PRASA): 200-year	✓	
Total model runs:	35	6

For the purposes of this report the twelve key 'monitoring points' indicated in Figure 4-1 were selected for comparison purposes throughout Section 4 in this report. These points were selected to represent areas where any impacts of the proposed developments are most likely to be realised / be of concern. If necessary, the models can be used for comparisons at any point within the modelling area.

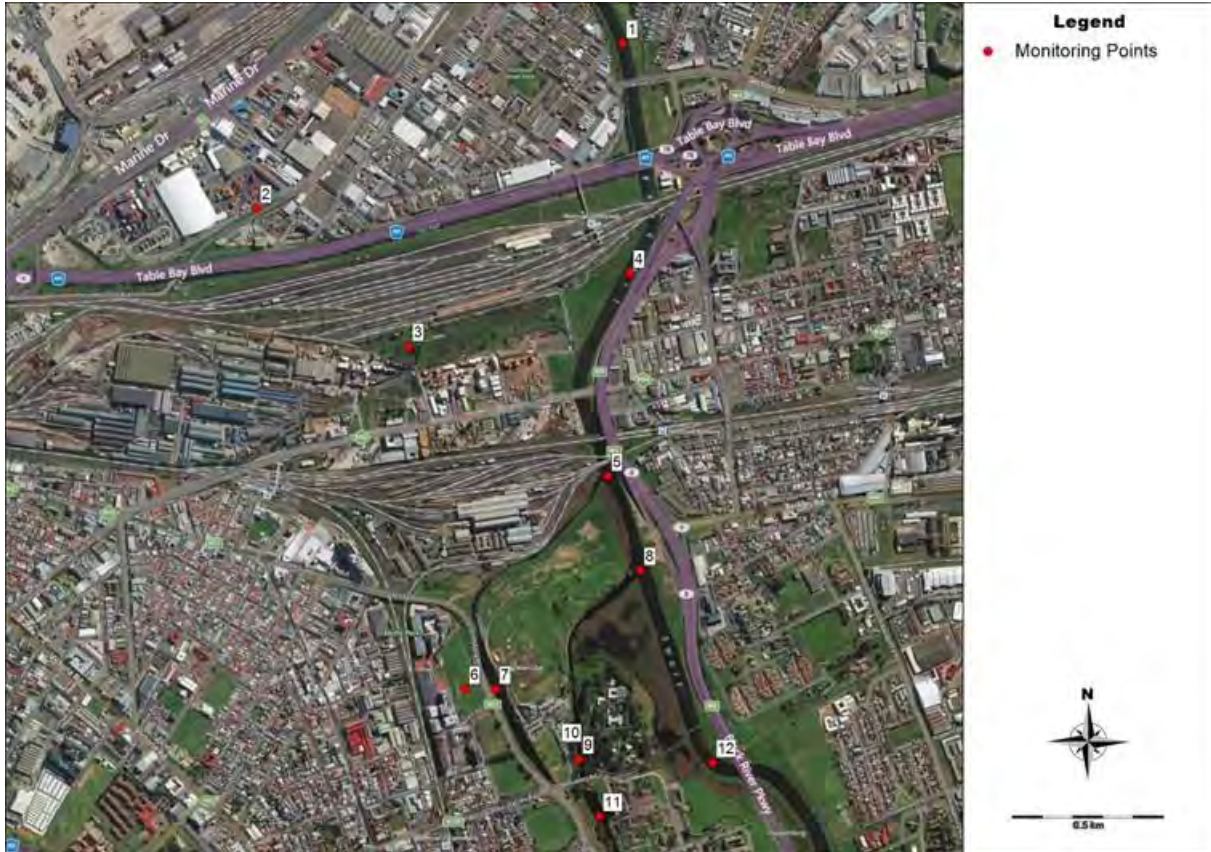



Figure 4-1 'Monitoring points' used for comparison between the different scenario's

4.1 Accuracy of the models

The PCSWMM models performed well, as all the models had 'routing continuity' and 'runoff continuity' errors of less than 1% which is considered acceptable (Rossman, 2008; CHI, 2017).

A comparison of the PCSWMM and HEC-RAS models showed the following:

- The HEC-RAS (Diffusion Wave model with the bridges modelled as 1D gates) and the PCSWMM models provided results that were within 0.01m of each other. Such differences were considered to be very good, especially considering the differences in ways that each of these programs models the flow.
- When HEC-RAS (Full Momentum equation with the bridges modelled as 1D gates) was used there appeared to be an increase in the backwater effect of the bridges immediately downstream of the River Club site. This appears to be as a result of a combination of adding the momentum component of the 2D equation and the manner in which the bridges were modelled (1D) within the 2D mesh. The results were compared with the results of previous models (especially Ninham Shand, 2004) and it seemed that the use of the full momentum equation with 1D elements within the 2D mesh (Bridges) resulted in some modelling instability.
- For both models the comparative increases in water levels between pre- and post-development were effectively the same.

- 
- When modelling the lower recurrence intervals it was possible to model the Bridges in 2D (by adding the piers into the model). For this scenario the results of the PCSWMM model and the HEC-RAS model were again within less than 0.1m. Unfortunately, as a result of the bridges all acting as controls, and the water levels potentially overtopping the bridges it was not possible to analyse the 1 in 100-year events.

All models have their limitations, however (with reference to Section 3.5) Aurecon is of the opinion that the models used for this investigation balance the complexity, uncertainties and data availability. PCSWMM and HEC-RAS both provided reasonable results in the 2D benchmark tests, and therefore the results presented herein, provide a reasonable basis for assessing the impacts of the proposed developments.

It is important to note that configuring the models was based on engineering judgement, and experience (Aurecon has more than 15-years' experience in this specific area), as there is no reliable data to calibrate the models.

4.2 Impact of the proposed development on flooding in the surrounding urban area

This section of the report presents and discusses the results of the modelling undertaken in order to determine the potential impacts that the proposed development might have on the adjacent properties.

4.2.1 Runoff from the site

The runoff from the site would have no impact on the flood level for a number of reasons:

- The conceptual design envisages a system of swales to attenuate and treat the flow – in accordance with the City's '*Management of urban stormwater impacts policy*' (CSRM, 2009b); and
- For larger storm events (e.g. 1 in 100-year recurrence interval flood events) the peak runoff from the site would occur approximately 1 to 3 hours before the peak flow in the adjacent rivers, and therefore the site's local runoff has an insignificant impact on the flows in the adjacent rivers

4.2.2 Flooding as a result of overland flow / minor system surcharging

Figure 4-2 highlights what is discussed in Section 2.1.7, concerning the flooding that occurs within the adjacent urban area and affects a number of houses. This flooding is the result of local overland flows that occur within the adjacent urban area when the local stormwater runoff exceeds the capacity of the local minor (piped) stormwater system. Figure 4-2 indicates that for storms equal to or smaller than the 1 in 20-year recurrence interval event local flooding in the highlighted area is a result of the stormwater system surcharging and resulting in overland flow.

As evident in Appendix B there is an increase in the extent of flooding extent of the Valkenberg wetland and the sports fields. It is Aurecon's view that the change in extent is exaggerated due to the computational and design of the model. As noted throughout this document the increase in water surface elevation that has been modelled is insignificant. It is more likely that during a storm event these areas will be inundated in any case.

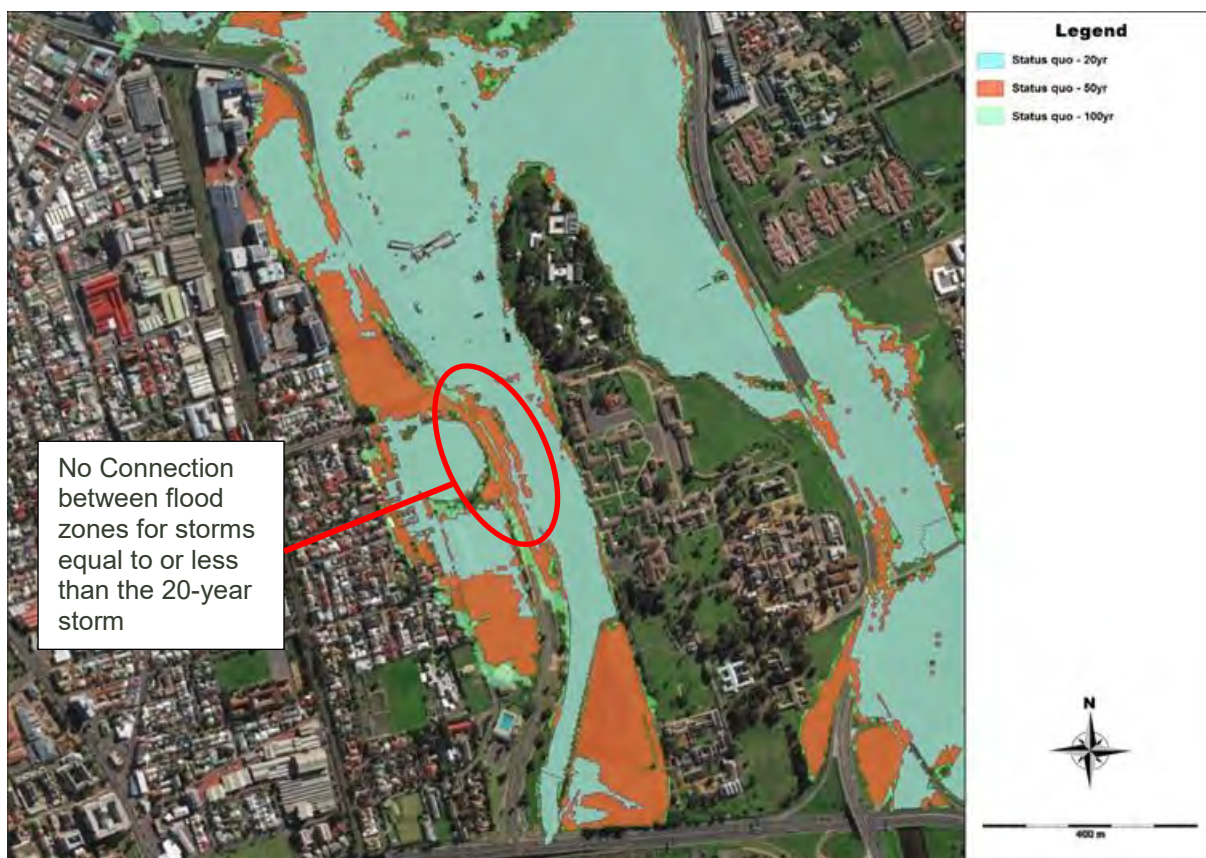


Figure 4-2 Flooding as a result of overland flow / minor system surcharging

4.2.3 Impact on water surface elevations

As expected, the most significant changes in water surface elevations would occur for the post-development scenario that includes the River Club, TRUP, PRASA and NRF developments. Table 4-2 provides a high-level overview of the differences in modelled water surface levels, based on the PCSWMM models, at 10 of the 12 monitoring points shown in Figure 4-1 – the results for all scenarios are provided in Appendix A. The TRUP development proposes that the sports fields along Liesbeek Parkway (Monitoring Point 6) are partially developed – resulting in no comparison between these two scenarios. Monitoring Point 2 consistently showed differences of between 0.01 m and 0.03 m for all recurrence intervals.

Table 4-2 indicates the following:

- For the 0.5-year and 1-year recurrence interval storm events the combined impacts of the developments would be small, possibly even reducing the water levels slightly. This is due to the small flows during these storms and the additional capacity, and perhaps the local attenuation volume that would be provided by the proposed new Liesbeek Canal design.
- The proposed developments would have minimal impact along the Salt River Canal. This is due to the canal overtopping and then flooding the neighbouring areas (Monitoring Points 1-4) except at Point 3 (appears to be in a wetland) at a low point where the level would increase by 0.08 m during the 1 in 5-year flood event.
- The greatest increases in water levels would be in the immediate vicinity of the River Club – Monitoring Points 5 through 12 – with the maximum expected increase in water level of up to 0.13 m (13 cm) for all flood events between the 1:5 year and 1:100-year return intervals.

- The impact of discharging runoff from the suburb of Observatory into the Liesbeek Canal (Post development scenario) rather than into the 'Old' Liesbeek, as well as cutting off the overland flow route over the River Club site connecting the Liesbeek Canal and the 'Old' Liesbeek appears to increase flow down the Liesbeek Canal and contributes to the increased water levels.

Aurecon would suggest consideration might be given to investigating ways of connecting the 'Old' Liesbeek and the Liesbeek Canal – this would aid in alleviating the above, negligible, effects.

Appendix A provides the results for the scenario where only the River Club is developed. While it is noted that the changes in water level are of a similar magnitude (differences typically +/- 0.00m – 0.03m) to Table 4-2. It is important to note that if each of the TRUP, NRF and PRASA sites were to be developed in isolation, these results do not mean that they would only have an impact equal to the difference (typically +/- 0.00m – 0.03m) between the post development scenarios including River Club, TRUP, PRASA, and the NRF sites and the post development scenario only including the River Club – as indicated in the RHDHV Study. This is due to the complexities of the hydrology and hydraulics in the vicinity of the River Club site.

Table 4-2 Summary of differences (m) in Water Surface elevation at the different monitoring points (Figure 4-1) between the existing status quo and the post development scenario (including TRUP, PRASA and NRF).

Recurrence interval (Description)	Monitoring Point									
	1	3	4	5	7	8	9	10	11	12
0.5-year	-0.04	0	0.01	0.01	Filled 'old' Liesbeek	-0.01	0.02	0	0.02	-0.02
1-year	-0.03	Has surface water	0	0.01		-0.03	-0.02	0	0	-0.01
2-year	0.02		0.02	0.04		0.01	0.04	0.03	0.04	0.01
5-year	0.02	0.08	0.02	0.04	-0.01	0.04	0.11	0.11	0.12	0.04
10-year	0.01	0.01	0.02	0.05	0	0.06	0.12	0.12	0.14	0.06
20-year	0.02	0.01	0.02	0.05	0.01	0.07	0.11	0.11	0.12	0.07
50-year	0.02	0.01	0.02	0.08	0.04	0.1	0.13	0.13	0.12	0.1
100-year	0.02	0.02	0.01	0.07	0.07	0.09	0.11	0.11	0.11	0.09
200-year	0.01	0.01	0	0.07	0.1	0.1	0.13	0.13	0.13	0.1
100-year (PRASA overland route closed)	0.02	0.01	0.01	0.08	0.1	0.1	0.12	0.12	0.12	0.1
100-year (Opened Salt River mouth)	0.02	0.01	0.01	0.07	0.07	0.09	0.11	0.11	0.11	0.09

The increases in water surface elevations shown in Table 4-2 need to be seen in the context of the uncertainties associated with modelling, the effects of wave action, the size of the storm event and the extent of inundation (as discussed in Section 4.2.4). In the light of all these considerations the increase in the modelled water surface elevations is relatively insignificant.

4.2.4 Impact on the extent of inundation

The increases in water level shown in Table 4-2 would result in limited changes in the extent of inundation for all recurrence intervals as is evident from Appendix B and discussed below. The relatively

minor local changes in the depths of inundation shown in Table 4-2 has little impact on the extent of flooding, and it requires a detailed inspection of the modelling results to identify differences in the extents of flooding – except for the 20-year where the extent increases into the Valkenberg wetland and into public open space. While the results for all the different scenarios are available – Appendix B – the only scenarios that would, potentially cause flooding of already developed properties are the 1 in 50-year flood event (Figure 4-3 and Figure 4-4) and the 1 in 100-year flood event (Figure 4-5 and Figure 4-6). These properties would be affected by flooding, to some extent whether the additional developments take place or not.

There are two minor exceptions where additional flooding would occur on account of overland flow. These are the properties discussed in Section 4.2.2 and the SAAO building which is discussed in Section 4.3. Therefore, the remainder of this section focuses on the main differences in flood extents for the 1 in 50-year and the 1 in 100-year recurrence interval storm events.

Figure 4-3 to Figure 4-6 show insignificant changes to the extent of flooding i.e. the area that would be flooded. The most noticeable changes are highlighted (Red Circles) and mainly comprise very shallow flooding on the PRASA site. The very small increases in the extent of flooding do not appear to compromise any infrastructure that is not already affected – most of the additional areas that would be flooded being railway lines. The other noticeable change is to the south of the modelling area as indicated in Figure 4-6, which would not have a significant impact on the existing flooding situation.

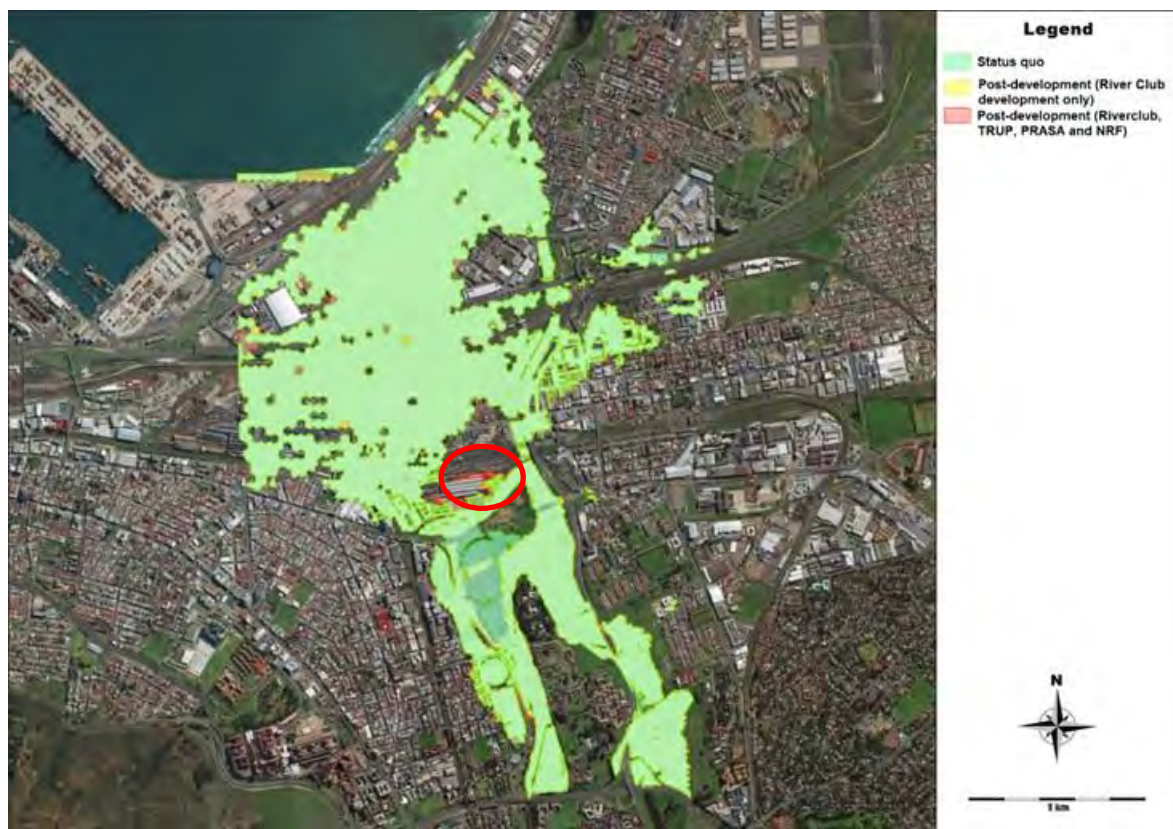


Figure 4-3 Maximum extent of inundation for the 50-year flood (whole model)

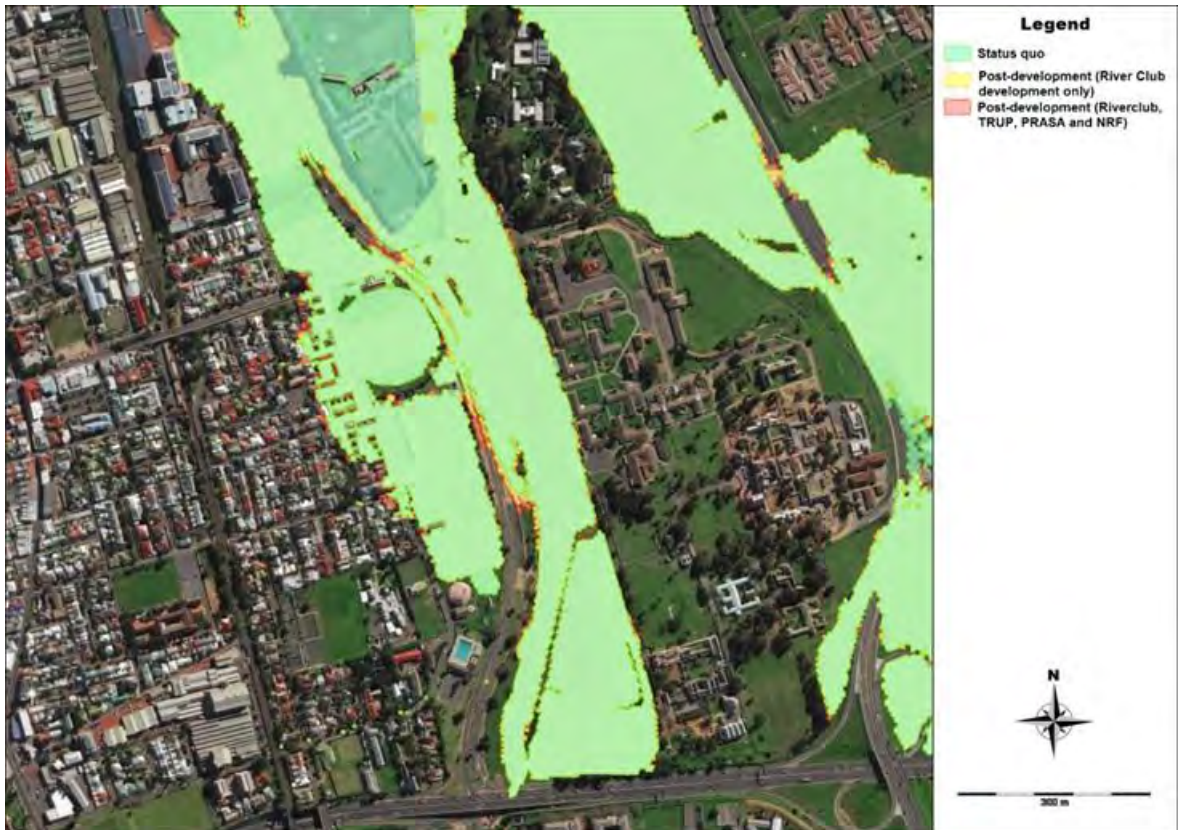


Figure 4-4 Maximum extent of inundation for the 50-year flood (Vicinity of River Club)

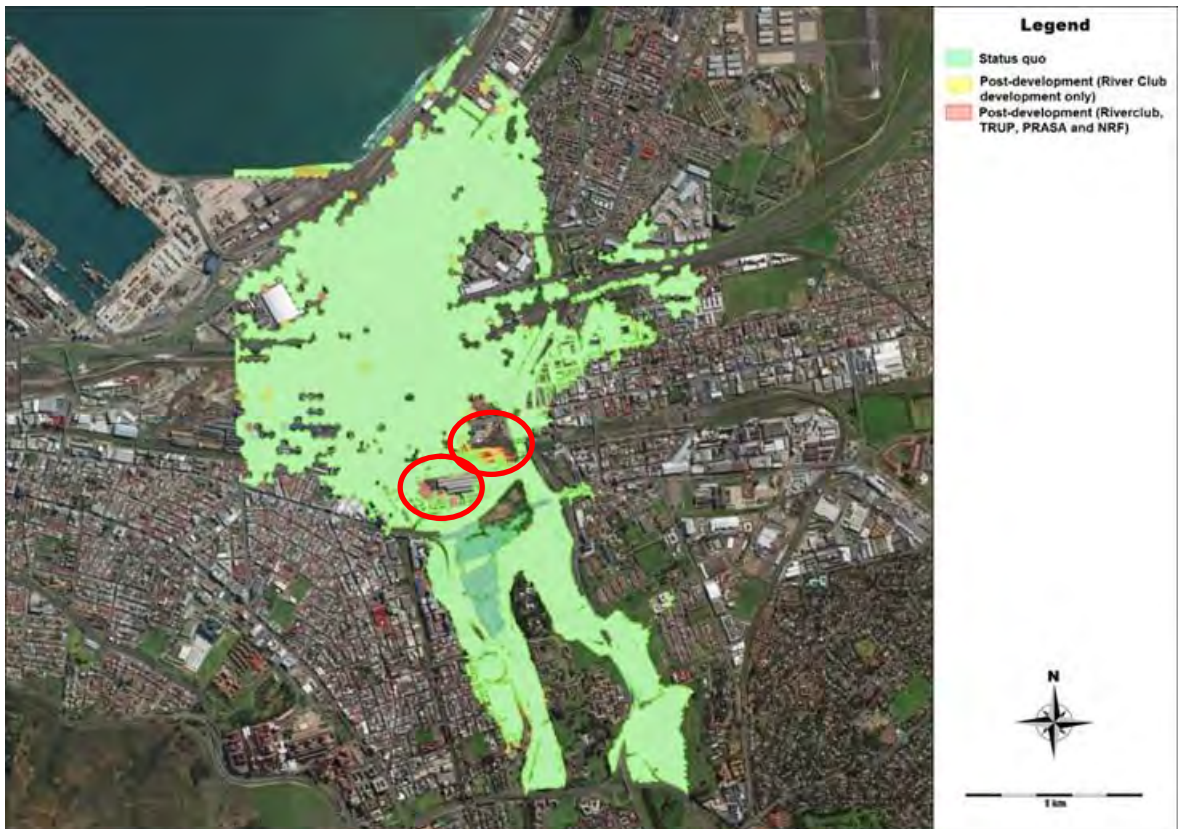


Figure 4-5 Maximum extent of inundation for the 100-year flood (whole model)

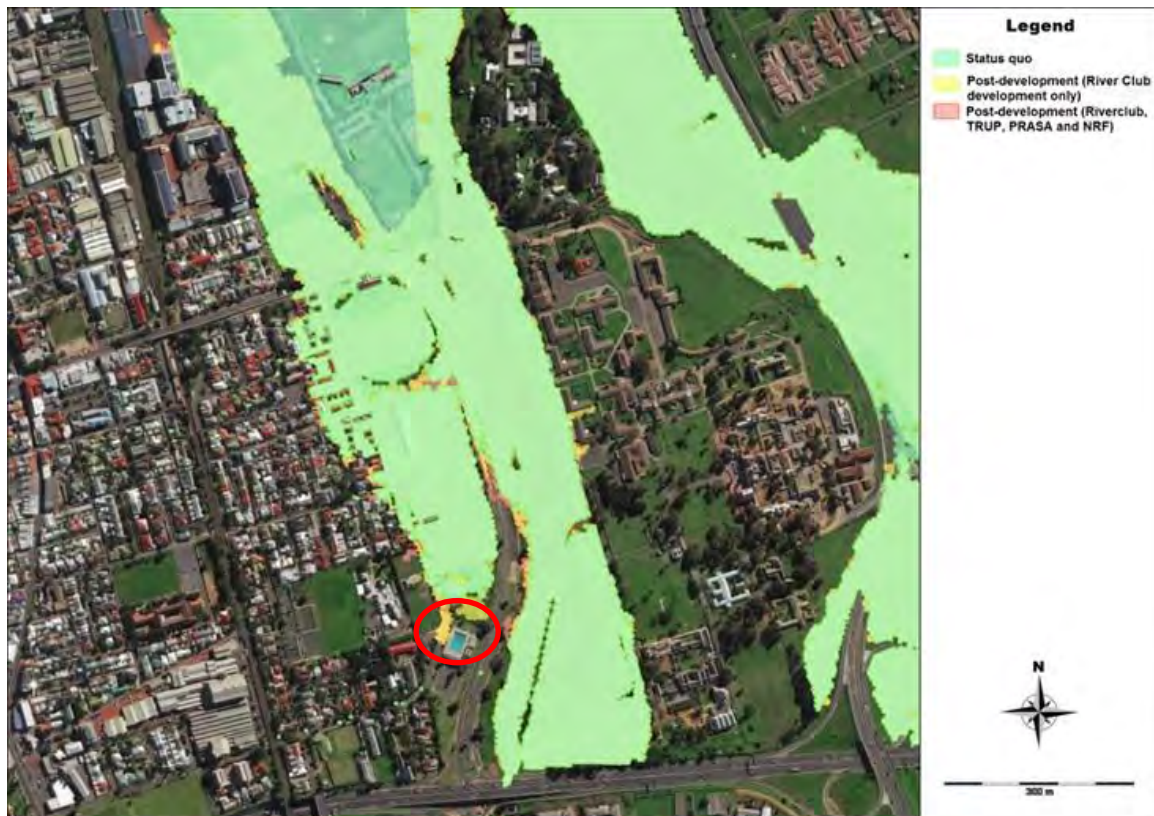


Figure 4-6 Maximum extent of inundation for the 100-year flood (Vicinity of River Club)

4.2.5 Changes in flow

The flows were assessed at the seven locations shown in Figure 4-7, and Table 4-3 provide a high-level overview of changes in the flow characteristics as a result of the proposed development/s.

Table 4-3 indicates the changes in the characteristics of the 1 in 100-year flood that would occur at various locations on account of the proposed developments. The main increases in flows would occur at the Salt Left and at the Black@River_Club. These increases are also evident from the hydrographs shown in Figure 4-8. The total volume of the flood at the Salt Left would increase by 4% as a result of the 7% increase in the peak flow. As discussed in Section 4.2.4, this change would have little effect on the aerial extent of flooding, as it would have little impact on the depth of flooding as discussed in Section 4.2.3. The additional flooding would also have little impact on the extent of the high hazard zone further downstream as discussed in Section 4.2.6. As the flood peak would occur marginally earlier as indicated in Figure 4-8 – which equates to a few minutes earlier rather than hours earlier and is thus of little significance.

The flow at Black@River_Club shows a significant, 24% increase in the peak flow that would occur for a couple hours. This increase in peak flow would occur because the proposed River Club development would effectively block the existing flow route that would have connected to the 'Old' Liesbeek River. This would force all the flow down the Liesbeek Canal route. This increased flow results in the slightly greater increases in flood levels in the vicinity of SAAO (Section 4.2.3). The effect though is localised along the course of the Liesbeek Canal (alongside the River Club site as is evidenced by the flow characteristics upstream (Black_River and Liesbeek) and downstream (Salt@Railway) in Table 4-3 and Figure 4-8. Figure 4-8 clearly demonstrates that the flow, and timing of the peak, under the railway bridges immediately downstream (Salt@Railway) is largely unaffected. As such, the effect is localised,

does not significantly affect any properties other than the River Club and SAAO, the impact of potential in the damage to property and the loss of human life is considered small. It is worth noting that the detailed design of the 'new' Liesbeek Canal, and extension to Berkley Road Bridge would need to account for the above changes in flow.



Figure 4-7 Locations at which flow was analysed

Table 4-3 High level overview of changes in the 1 in 100-year flood characteristics as a result of the proposed developments

Objective Function	Black @ River Club		Black River		Liesbeek		PRASA Overland		Salt Left		Salt Right		Salt@Railway	
	Status Quo	Post-development	Status Quo	Post-development	Status Quo	Post-development	Status Quo	Post-development	Status Quo	Post-development	Status Quo	Post-development	Status Quo	Post-development
Maximum Flow(m ³ /s):	202.2	249.1	212	215.1	96.29	96.38	6.046	9.319	125.4	134.2	*		242.5	249.9
Minimum Flow(m ³ /s):	13.86	15.67	11.13	12.3	-1.428	-1.054	-0.1065	-0.1359	-0.02391	-0.01814			16.05	16.51
Mean Flow(m ³ /s):	106.4	121.7	97.28	97.26	24.81	24.59	0.5272	0.8095	35.72	37.11			123.4	123
Total Flood Volume(1000m ³):	10930	12490	9990	9988	2548	2525	54.14	83.14	3669	3811	-462.3	-486.3	12680	12640

*Due to a significant stormwater culvert crossing the flow path the estimation of peak discharges is distorted

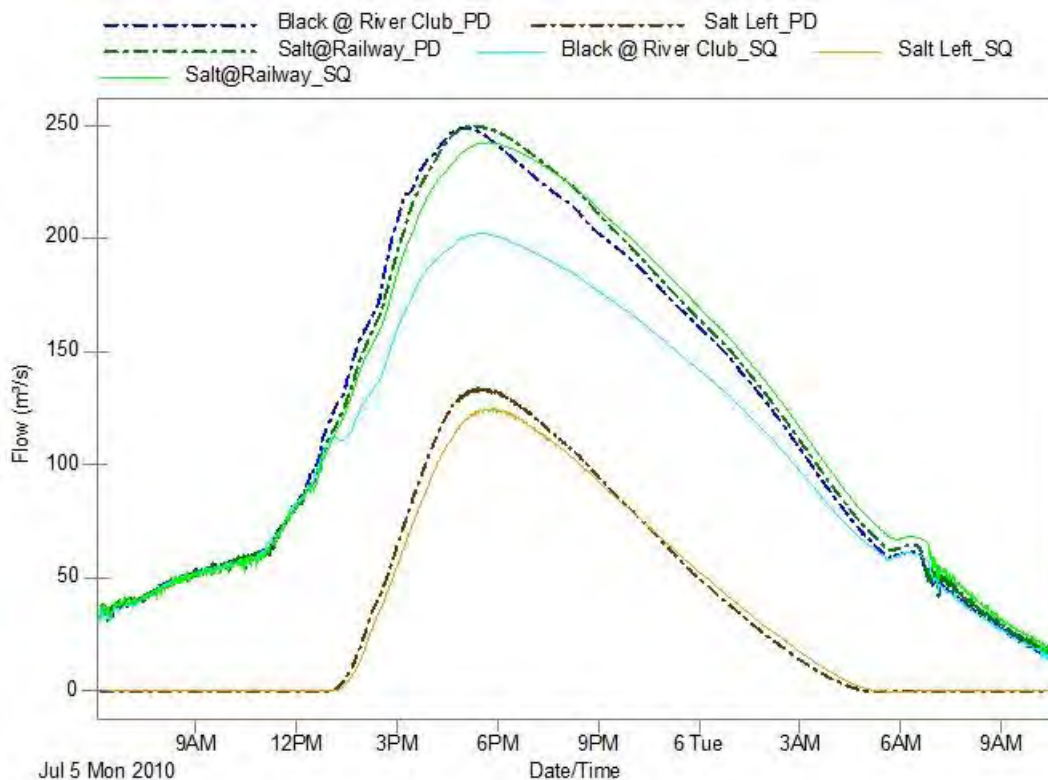


Figure 4-8 Hydrographs at locations where noticeable changes in flow were detected (SQ = Status quo; PD = Post development with NRF, TRUP, PRASA, River Club)

4.2.6 Environmental and Proposed Development Considerations and Constraints

The increased water levels at Monitoring Point 5 shown in Table 4-2 and in Figure 4-1 arise mainly from the additional losses at the railway bridges on account of the higher flows. The additional increases in water levels further upstream appear to arise from the following:

- The increased flow in the channel between Points 5 and 8 with no improvements to the channel.
- The proposed configuration of the channel from Points 9 and 10 which was determined in accordance of the environmental constraints which include the approximately 25 m wide buffer strip to be provided within the boundary of the proposed River Club development.

4.2.7 Hazard Analysis

The hazard analysis indicates that currently a significant portion of the River Club Site falls within the High Hazard zone. In terms of the City's 'Floodplain and River Corridor Management Policy' (CSRM, 2009a) development would not be allowed. Should the development be elevated out of the flood plain – as is proposed – and there be adequate, safe access the development would no longer fall within the High Hazard Zone. This would however require a deviation from Section 9.2 of the City's 'Floodplain and River Corridor Management Policy' (CSRM, 2009a) which prohibits new or existing rights within the High Hazard zone – and considers 'Filling' as development.

The analysis indicates rather limited changes to the type and extent of flood hazards – highlighted in Figure 4-9 and Figure 4-10. The impacts at the locations of the numbered circles in Figure 4-10 are described below:

- Circles 1 & 2: The affected area on the PRASA site is discussed in Section 4.2.4. This increase would have little or no impact.
- Circle 3 highlights a potential change in hazard that appears to border / incorporate one lane of Liesbeek Parkway. This could have a significant impact. It is necessary to raise the road locally – where the hazard changes and for a short distance (e.g. 50m either side), as agreed with the City, to eliminate the potential high hazard caused by flooding in the 1 in 100-year. There would also be value providing warning signs.
- Circle 4 highlights the increase hazard evident in the vicinity of the Hartleyvale sports complex. This increase hazard is very localised and unlikely to have any impact – the area would normally be flooded and is unlikely to be used during extreme events such as the 1 in 100-year storm event.
- Circle 5 highlights that the existing Berkley Road is within the 100-year flood line and low hazard zone. This is section of road is also affected in storm events greater that the 1 in 20-year event. This should be considered and analysed in the final design

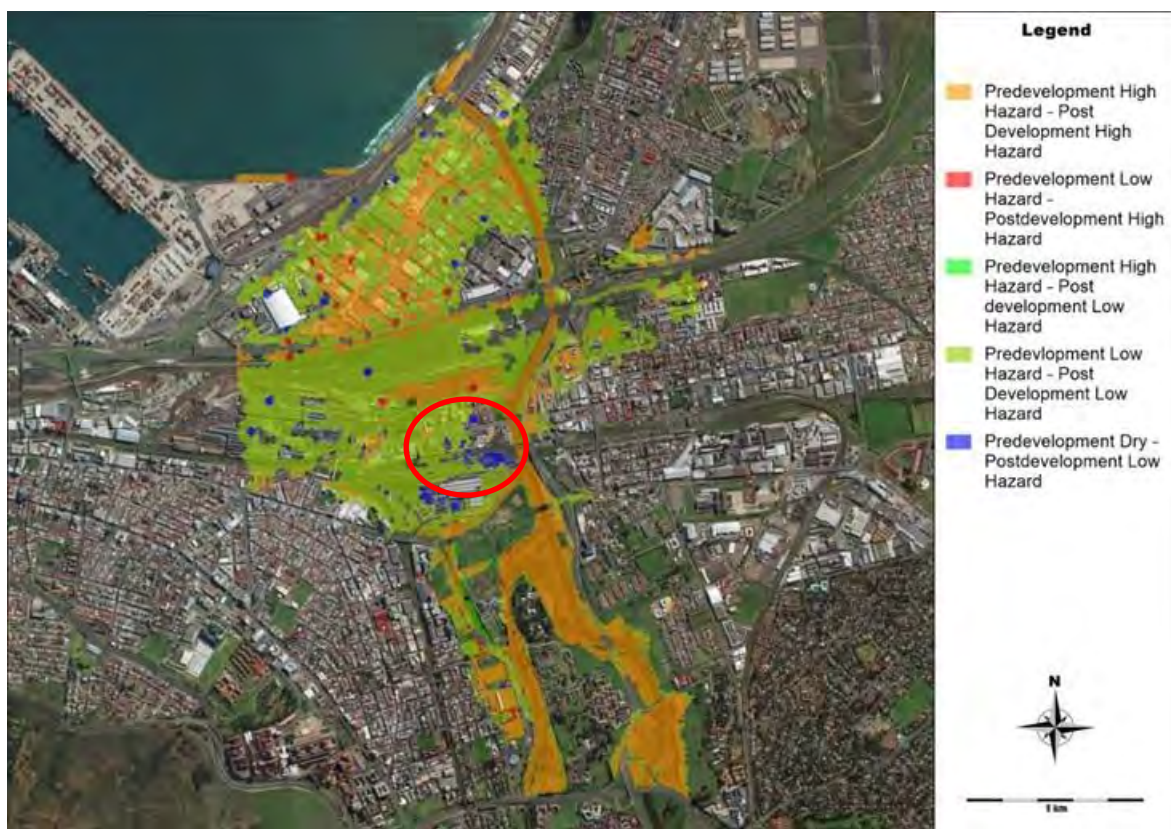


Figure 4-9 Impact of the development of the hazard of flooding (Whole model)

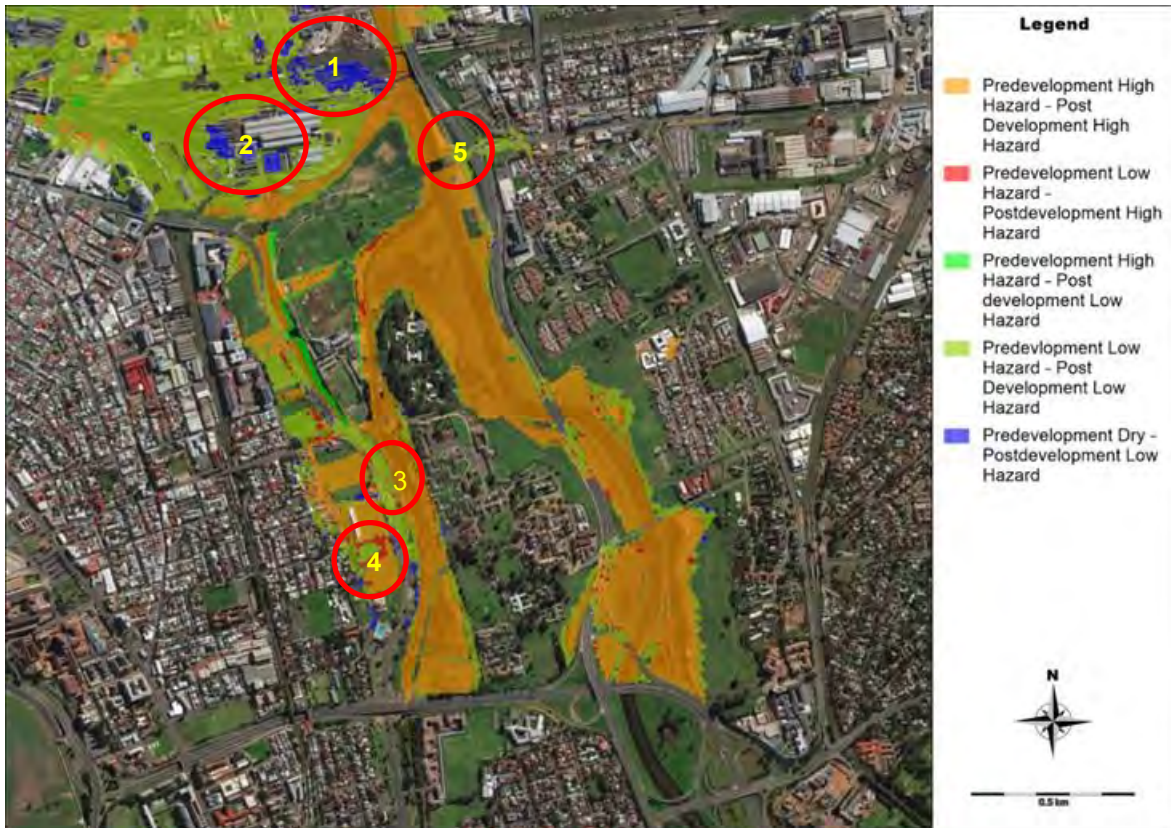


Figure 4-10 Impact of the development of the hazard of flooding (In the vicinity of the River Club)

4.2.8 Impact of the closure of the PRASA overland escape

The analysis of the impact of closing the PRASA overland escape route indicated, surprisingly, that it would have an insignificant impact on the extent of inundation during a storm event – as indicated in Figure 4-11 – assuming the flow through the bridges downstream of the site remained unobstructed. The change in water surface level for the 1 in 100-year flood event remains small at the monitoring points as highlighted in Appendix A.

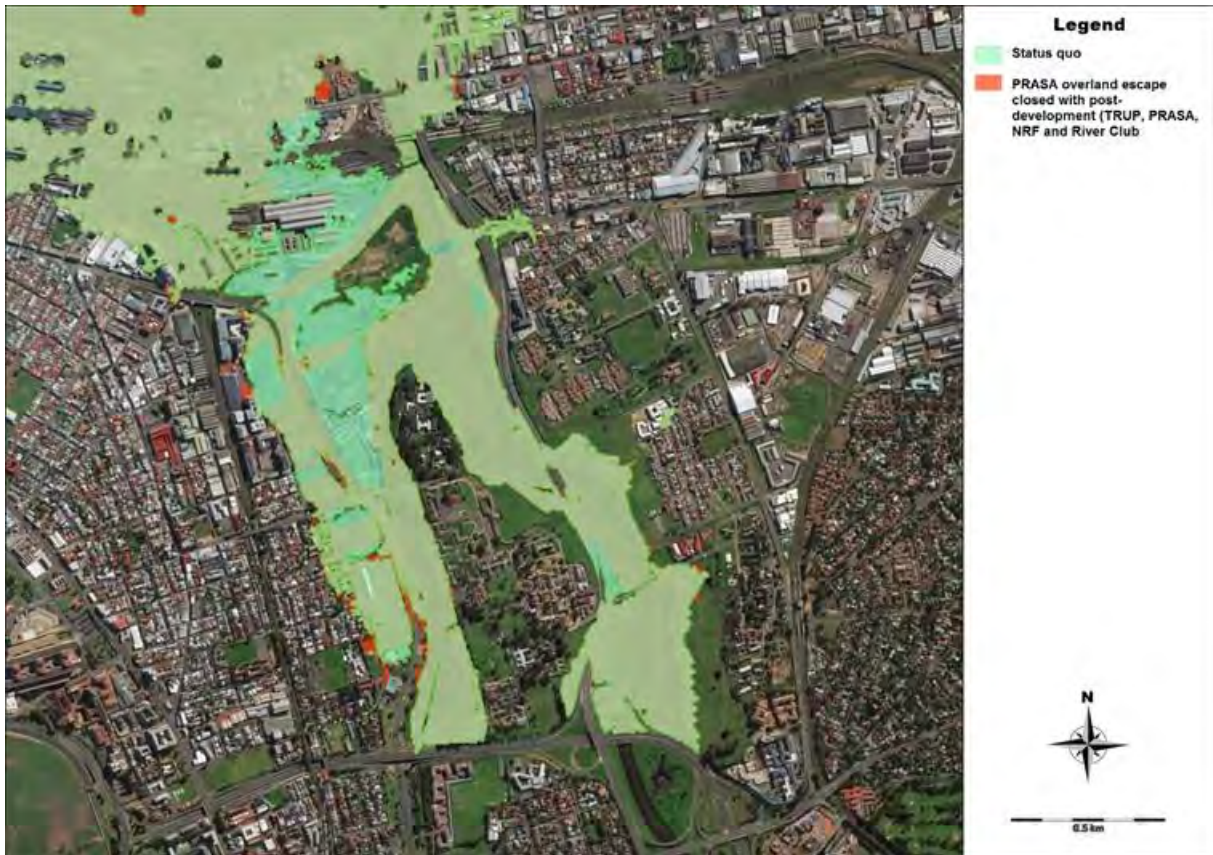


Figure 4-11 Impact on flooding of possible PRASA escape route during the 100-year Storm event

Should the flow through the bridges become obstructed (e.g. by debris flowing down the river) the importance of the PRASA escape flow route would increase. Therefore, it would be preferable for the City to ensure that this escape route is maintained for the following reasons:

- Should, for any reason, the railway bridges immediately downstream of the River Club site become blocked, the PRASA escape route would become critical – as shown in Figure 4-12.
- Once such a flood route is closed it is unlikely that it would be possible to re-establish it.



Figure 4-12 Impact of partially blocking the railway bridge immediately downstream of the River Club site

4.2.9 Impact of Sea Level rise

For the TRUP study conducted by RH-DHV (2017), which is discussed in Section 3.1.5, the City and RH-DHV agreed on certain boundary conditions based on the recommendations of PRDW which are discussed in Section 3.1.5 and summarised in Table 3-2 (PRDW, 2010). PRDW (2010) noted that preliminary results indicate that extreme rainfall events should be considered with storm surge events of a lower return period (i.e. 1 in 10 year storm surge – for which they did not offer an estimate in their study – with a 1 in 100 year flood event). As the City and RH-DHV had already agreed to using the 1 in 50 year storm surge with a 1 in 100 year flood event for the TRUP study and the surface water hydrology study is particularly contentious, Aurecon decided to use what RH-DHV had agreed with the City – 50 year storm surge. However for completeness, Aurecon also modelled the 10 year storm surge with a 100 year flood event. The results of the modelling are shown in Figure 4-13 which indicates very little difference in the extent of flooding. Aside from the area around Paarden Eiland, the water surface elevations remain within 1 cm (0.01 m) of each other – well within acceptable modelling error. There is a slight greater difference in modelled water surface elevations in the vicinity of Paarden Eiland – approximately 0.08 m – which is likely due to slightly less flooding from the canal and lower estimated tidal levels, but this is independent of the proposed developments and rather the selection of boundary conditions

These results are not entirely surprising as the tidal levels in Section 3.1.5 make provision for 0.55 m to account for sea level rise as a result of climate change and a storm surge which together add more than 0.8 meters to the Mean High Water Spring tidal level – which was used for previous studies. This larger sea level rise would seriously constrain the capacity at the outfall, likely contributing to the flooding. An investigation of the impacts of sea level rise is beyond the scope of this study, however it would be in

the City's interest to undertake further modelling to assess how climate change and sea level rise impacts could be mitigated.

Another reason for the limited differences, regardless of the tidal levels, is that a significant portion of the flooding is as a result of the Salt River exceeding its capacity. However, as discussed in Section 4.2.10, even if the Salt River Canal were to be widened, the benefit would be relatively minor.

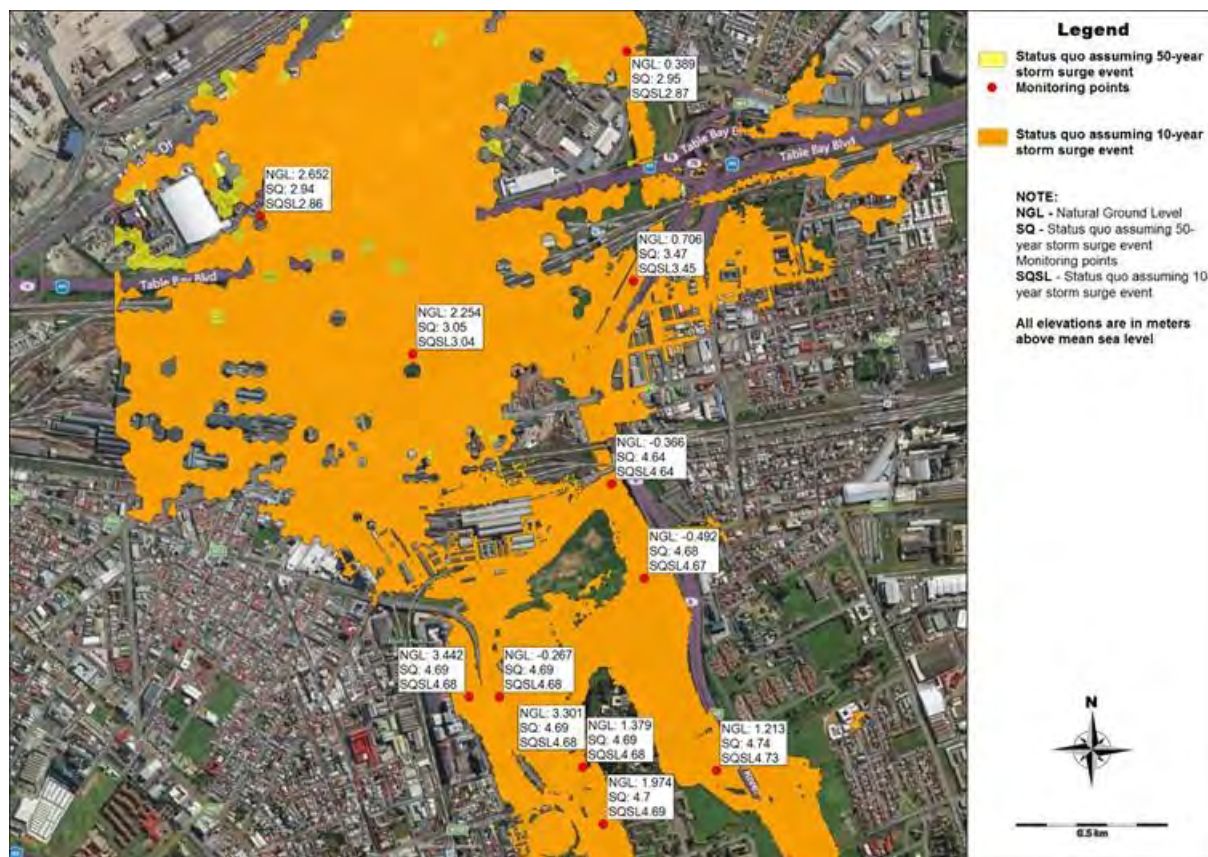


Figure 4-13 Comparison of the inundation considering the 100-year flood event in combination with the 50-year and 10-year storm surge events

Effectively this study indicated that due to the projected sea level rise, resulting from climate change, there would be flooding in the lower parts of the catchment – regardless of whether the development went ahead or not, and that the development is unlikely to have any effect on the extent of flooding.

4.2.10 Impact of widening the Salt River Canal

The City requested that this study should also consider the possible effect of widening the Salt River Canal and removing any restrictions (e.g. bridges). As discussed in Section 3.7, the modelling of this scenario would represent the 'absolute best case'. In Aurecon's view, such improvements are unlikely to ever be realised for a number of reasons, including both practical and economic considerations. The modelling considered the 1 in 100-year storm event and the following scenarios:

- Existing status quo (existing channel and development) – SQ;
- The status quo (existing development) with a widened channel (Section 3.7) – SQW; and
- The proposed River Club development together with the proposed TRUP, PRASA and NRF developments and a widened channel – PDTW.

The results which are summarised in Figure 4-14 indicate that widening the channel and removing the hydraulic effects of the bridges would reduce the maximum water surface level by between 0.1m and 0.8m. Interestingly this would have little impact on the extent of inundation, except as follows:

- The sports fields would not be inundated as the 'old' Liesbeek would not over top, although the fields would be lower than the water level in the canal and thus would be considered to be within the floodplain; and
- The PRASA land, also because the 'old' Liesbeek would not overtop.

There are some other minor differences between the status quo and the post-development scenarios with the Salt River Widened. These are most marked near the existing entrance to the River Club site about 0.35m. This effect is localised. For both scenarios with the widened Salt River channel, the extent of flood inundation would be reduced – but not significantly.

Widening of the canal would potentially have a negative environmental impact on the Raapenberg Wetland due to the lower water levels which would result in the wetland being flooded less frequently. Therefore, unless the value of development on the PRASA site were significant or critical as part of long-term city/town planning and the City were to undertake further modelling of the design of any widened channel, it is unlikely that widening the Salt River would be an economic or practical solution to flooding in the Salt River Catchment – whether the River Club development goes ahead or not.

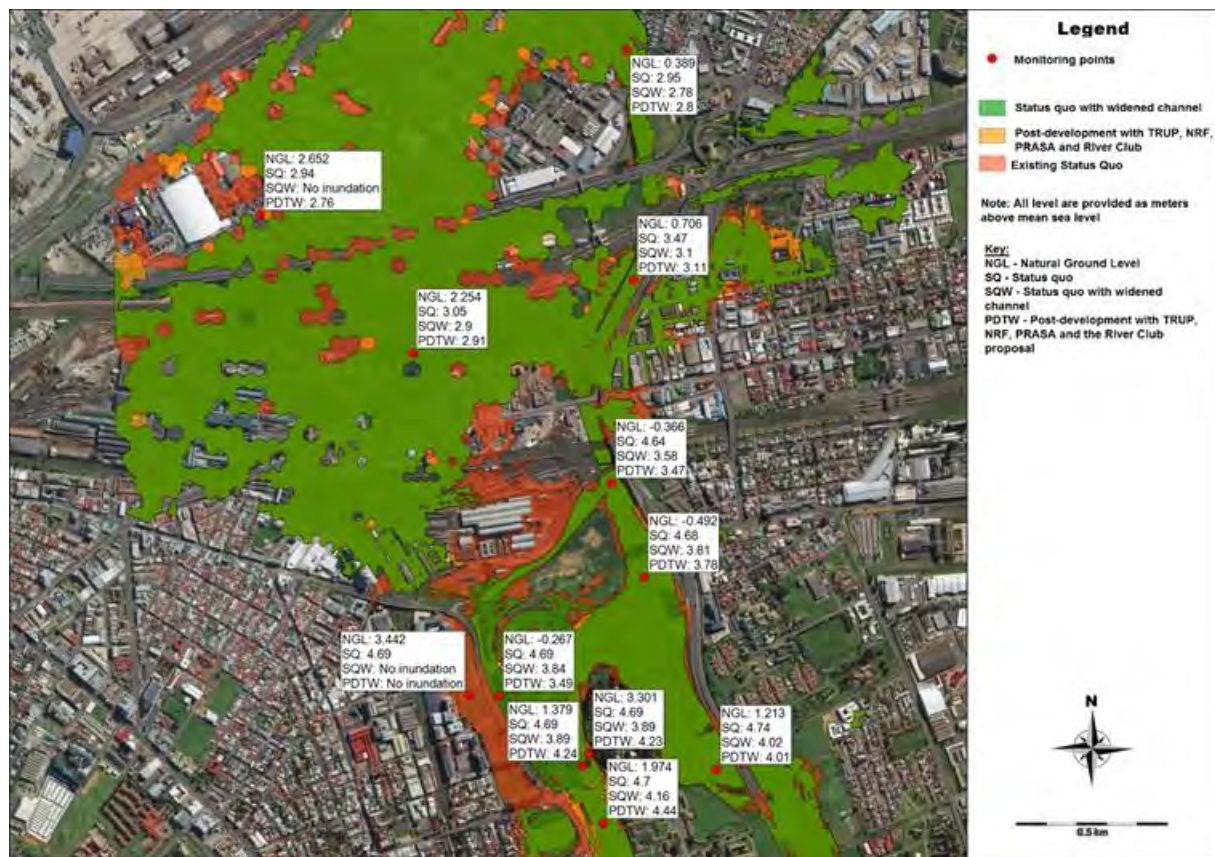


Figure 4-14 Impact of widening the Salt River on the extent of inundation of the 100-year flood

4.2.11 Sensitivity analysis

The sensitivity analysis, discussed in Section 3.12, indicated that although the proposed River Club and other developments would cause small increases in flood levels (as expected due to the increases in flow), the maximum differences between pre- and post-development flood levels would only be about 0.01 m (10 cm). Even if future models indicate increased or decreased flows in the Black and Liesbeek Rivers, it is likely that these would show similar differences in the pre- and post-development flood levels.

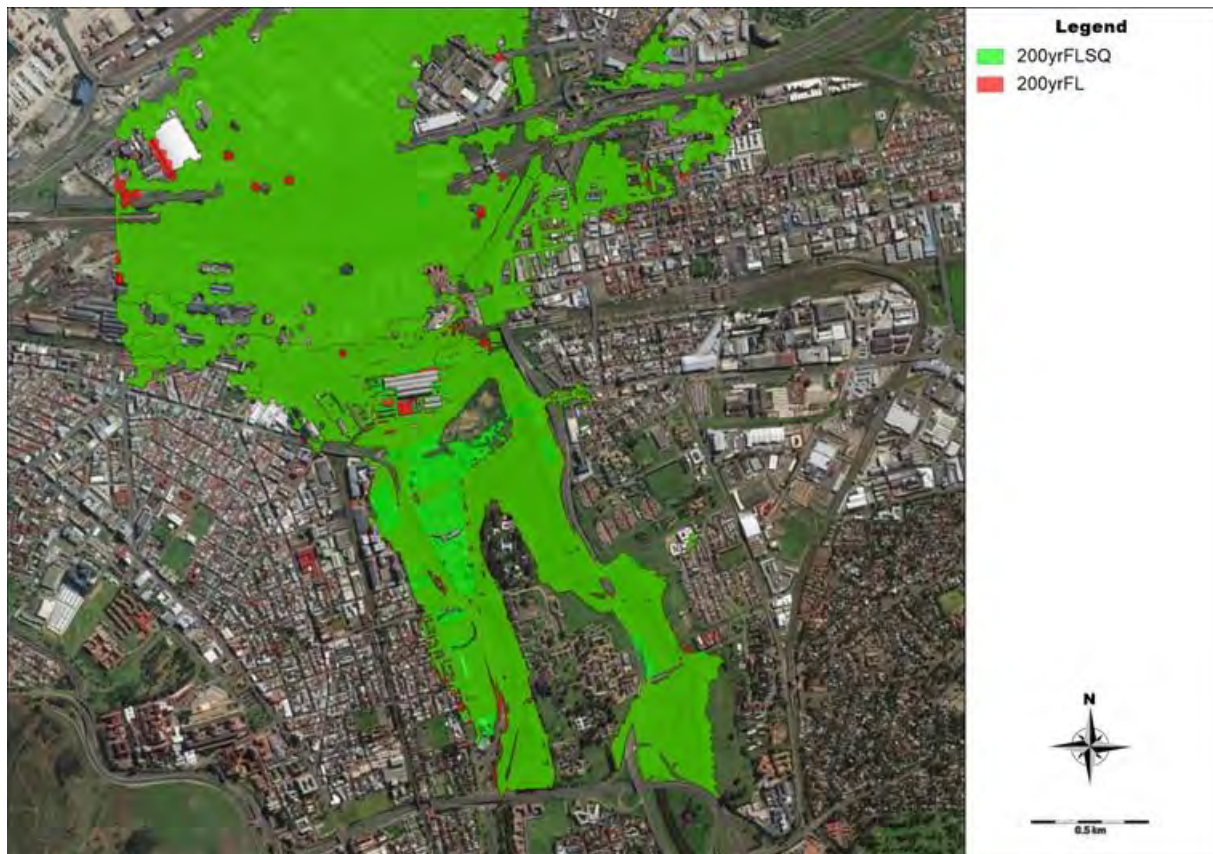


Figure 4-15 Maximum extent of inundation for the 200-year flood (whole model)

4.2.12 Summary of the analysis

It is evident that the modelling results show that “no matter what” is done, the impact is “insignificant”. This is borne out by the following:

- The development of the River Club, along with the TRUP, PRASA and NRF sites is likely to have an impact on flood levels, in the order of, 0.01m – 0.15m depending on the storm recurrence interval and location. With the greatest differences expected in the vicinity of the SAO.
- The insignificant changes in the extent of inundation whether the River Club proposal is taken forward in isolation or in combination with the TRUP, PRASA and NRF proposals;
- The insignificant changes in the extent of inundation when the PRASA overland escape route is closed;
- The insignificant changes in the extent of inundation for minor storm events that may have an impact on the functioning of the Raapenberg Wetlands; and

- The insignificant change to the extent of inundation, when the 10-year or 50-year storm surge is used as a boundary condition.

This is not entirely surprising as the River Club site is located in what historically was an extensive wetland which likely drained to the ocean as discussed in Section 2.1. As discussed in (Brown & Magoba, 2009) the site itself is in places only 2 m above mean sea level and the slope of the canal to the ocean is very flat, in some areas it is completely flat, and there are a number of hydraulic obstructions along its route (e.g. bridges).

4.3 Impact of the proposed River Club development on the SAAO buildings

4.3.1 Impact of developing the River Club and surrounding sites

Assessing the impact of flooding on the SAAO buildings is complicated as the SAAO has constructed its own berm (Section 2.1.4). As noted in Section 2.1.4, these berms were not considered as part of this analysis. The analysis was further complicated as some of the buildings indicated in Figure 4-16, some which might also have heritage value, were developed in what is clearly the flood plain and are therefore are prone to flooding.



Figure 4-16 SAAO buildings on the edge of the Liesbeek River canal. Dark blue – 3 – buildings are considered to have possible heritage value

The modelling indicated that for the 1-year recurrence interval storm event, none of the buildings would be flooded under any development scenario and that there would be no flooding onto the SAAO property. The modelling indicates that for the 1 in 2-year recurrence interval storm event the land surrounding the buildings would be inundated and that there is a high likelihood that water would enter Building 1 as evident from Figure 4-16. For the Status Quo scenario the water level around the building (3.36 mamsl) would be just below floor level (3.33 mamsl) during the 1 in 2-year flood whereas for the

post development scenarios (River Club Including / Excluding TRUP PRASA, NRF) the modelled water surface elevation would be 3.6 mamsl and 3.7 mamsl.

As mentioned throughout this report, the modelled results should be carefully considered, especially considering small differences in water levels of less than 0.1 m. However, for the post development scenario Building 1 (not identified as having heritage value) would be flooded slightly more frequently and its floor is likely to be damaged by the 1 in 2-year flood and by all larger flood events. Therefore, for the post development scenario the frequency of damage may be increased. Quantifying the differences in damage is not possible – except to indicate that this would be marginal.

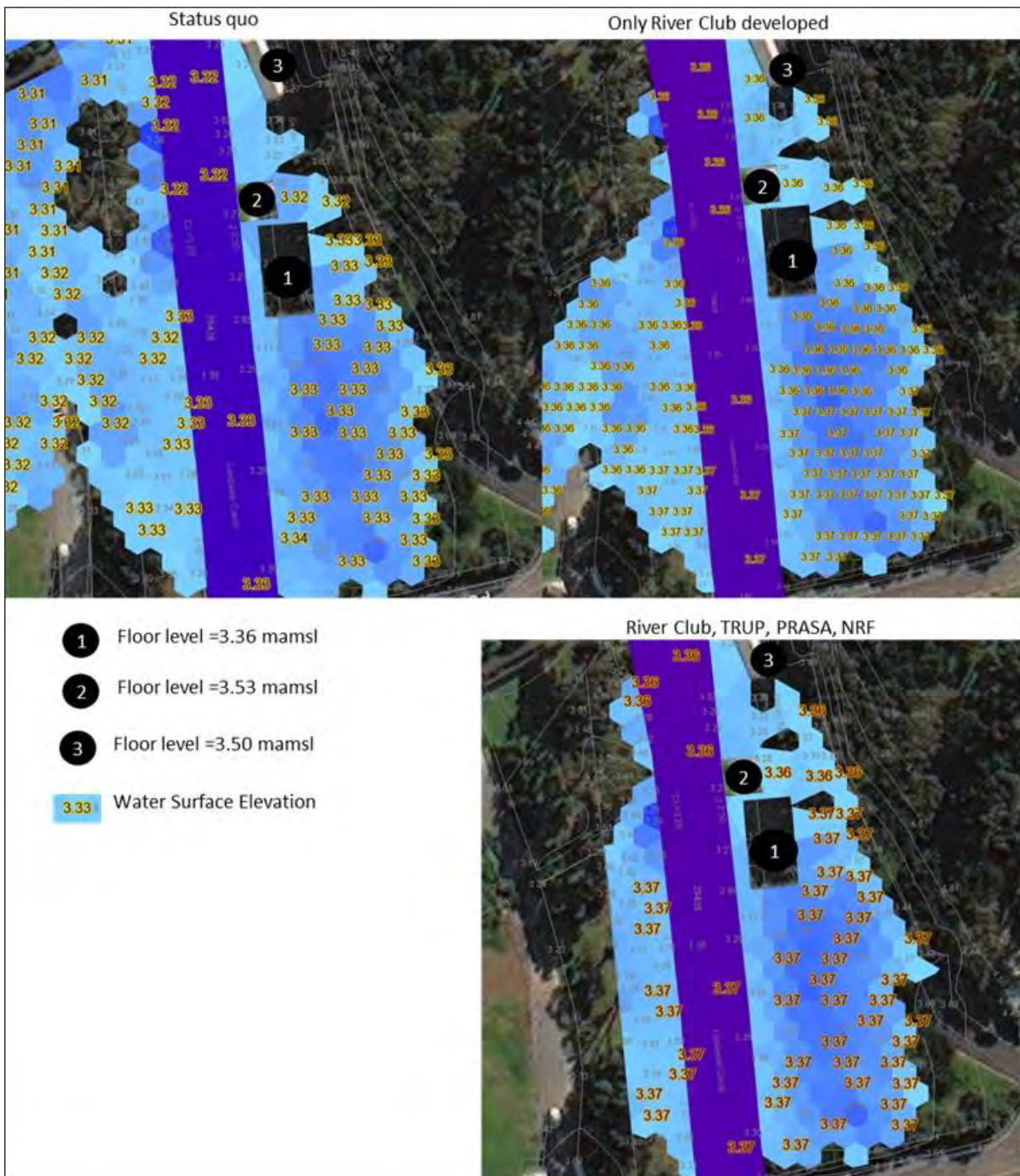


Figure 4-17 Impact on flooding during the 2-year recurrence interval storm event for various development scenarios

For the 5-year recurrence interval storm events, all the buildings of concern would be inundated by flood water. The differences between the status quo and the post-development scenarios are evident from Figure 4-18 – an increase in depth of 0.12 m (12cm). It is worth noting that the floor level of Building 3 (which has heritage value) is 3.50 mamsl and therefore the building would be inundated about once in 5 years to a depth of about 0.15 m deep. Although the increased depth would have an impact, this would not have a significant impact on the cost of repairs as the 1 in 5-year water depth in the building would be less than 0.3 m.

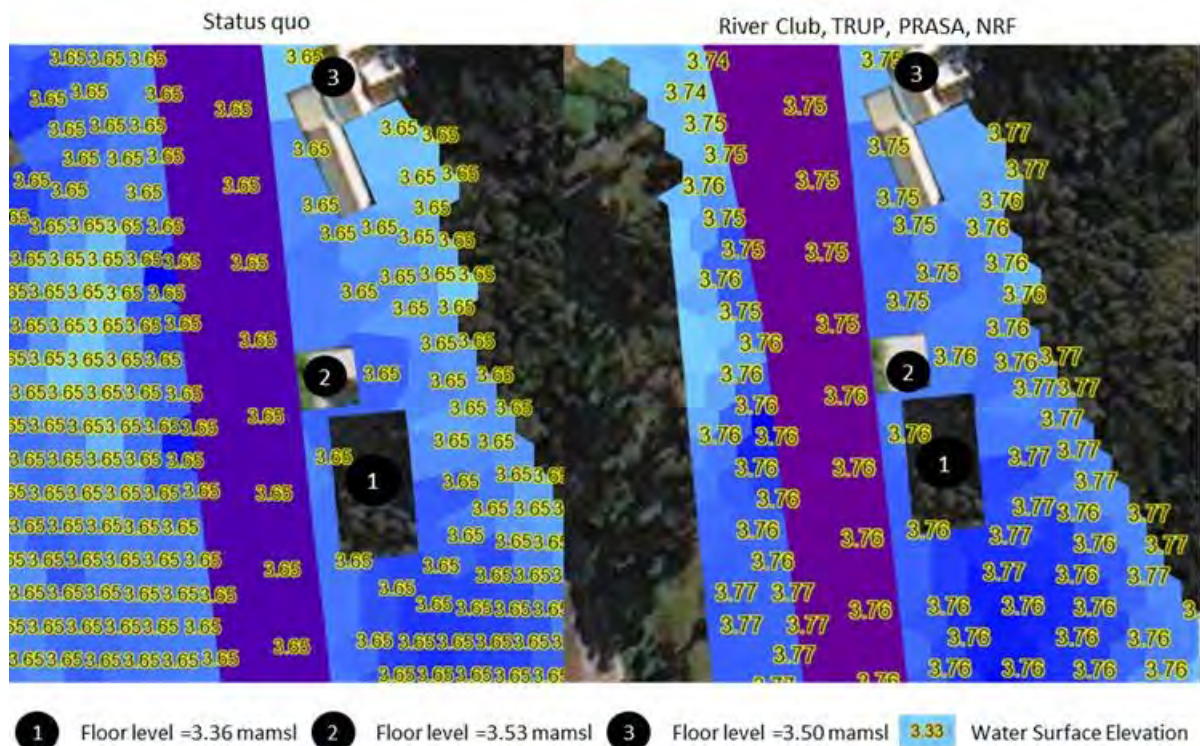


Figure 4-18 Water surface elevations during the 5-year recurrence interval storm event for different development scenarios

For larger storm events the pre- and post-development impacts would be similar with very slightly higher flood levels for the post development scenarios.

4.3.2 Mitigation options

It is important to recognise that these properties were built within the 1 in 2 to 1 in 5-year flood plain and therefore are prone to flooding. The only real option to protect these buildings would be to construct a protective berm. As mentioned in Section 2.1.4, without the knowledge of the City's stormwater department the SAAO constructed a berm along the boundary of their property. The top of the berm varies between 3.6 mamsl and 4.14 mamsl. It is likely that this will only protect the SAAO buildings from the 1 in 2-year recurrence interval storm events. This berm could be raised to protect these properties, from larger storm events. Raising the crest the berm to about 4.8 mamsl would provide protection for the 100-year recurrence interval event although this would pose a significant risk to the occupants of

the buildings if the berm failed. The berm would probably not have any significant impact on flooding elsewhere.

4.4 Impact of the proposed development on flooding in the surrounding ecosystems

In Section 3 it was mentioned that estimating the rainfall for a storm with a recurrence interval of less than about 1 in 2 years is statistically problematic. Based on the modelling undertaken as part of this study – both in PCSWMM and HEC-RAS modelling - it would appear that the wetlands would receive inflows from the Liesbeek Canal when the water surface elevation is in the region of about 2.5 mamsl as indicated in Figure 4-19. This would equate to the wetland filling in a storm with a recurrence interval of between ½-year and 1-year. Once water enters the wetland, and the wetland is filled to +2.5 mamsl the wetland becomes part of the flood plain area offering limited offline storage. The wetland does not appear to drain below a level of +2.5 mamsl (the level at which flow enters the wetland). This would equate to approximately 1 m of standing water at the deepest points in the wetland. It seems that this water evaporates over time. Evaporation at Observatory is estimated to be approximately 1.5 m/annum, and rainfall about 0.6 m/annum. This would suggest that over a typical / average year the water levels would fluctuate in the wetland. If there were successive droughts – as in 2015, 2016, 2017 – it is possible that the wetland could dry out should there not be a storm of sufficient magnitude to result in flooding into the wetland.

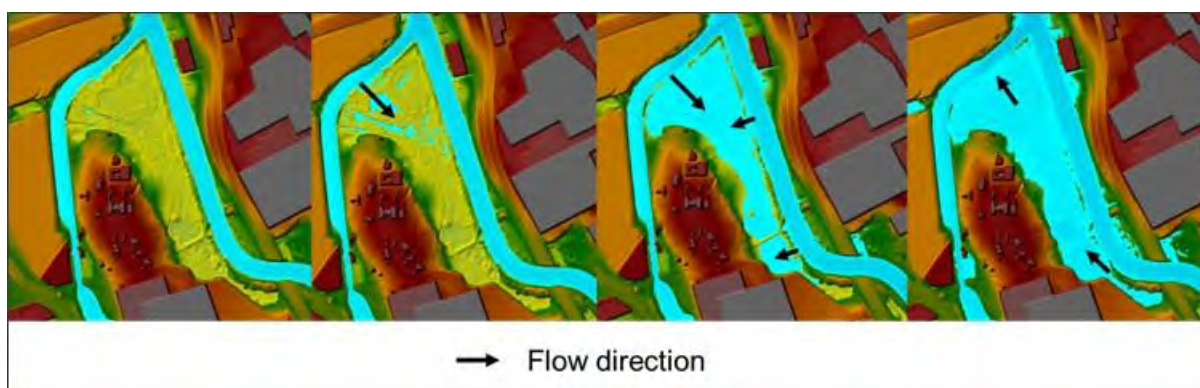


Figure 4-19 Overview of how flow enters and then leaves the Raapenberg wetland

The intervention undertaken by the Friends of the Liesbeek, TRUPA and SAAO which is shown in Figure 3-12 has effectively reduced the level at which the wetlands are likely to fill and empty, to about 2.25 mamsl. While Dr Day (Freshwater Consultant) will address the potential impacts of the increased frequency of inundation on the ecology, the intervention effectively has the impact of adjusting the level to which the wetlands would drain after flooding to about 2.25 mamsl (instead of about 2.5 mamsl). This equates to 250 mm lower. Assuming an evaporation rate of about 4 mm/day, the reduced water level would equate to a reduction of about 60 days before the water volume stored in the wetland is evaporated away. This could be compensated by more frequent flooding, but it is Aurecon's understanding from Dr Day, that an increase in flood frequency may have a negative impact on the wetlands performance as it could decrease the salt levels in the wetland.

An interesting observation on site which is confirmed by the survey, is that the water levels in the Black and Liesbeek Rivers are higher than the water level in the wetland by approximately 100-150 mm – Figure 4-20. This indicates that the wetlands are not, typically, filled with water from the surrounding rivers – although the hydraulic gradient would indicate a flow direction into the wetlands. In fact, it would appear that the hydraulic conductivity of the soil / peat that makes up the wetland is equal to or lower

than the evaporation rate. The part of the wetland South of the footpath extending from Observatory Road towards the M5 appears to be connected to the river System at some point upstream and also has a higher surface water level than the primary wetland that borders the SAAO.

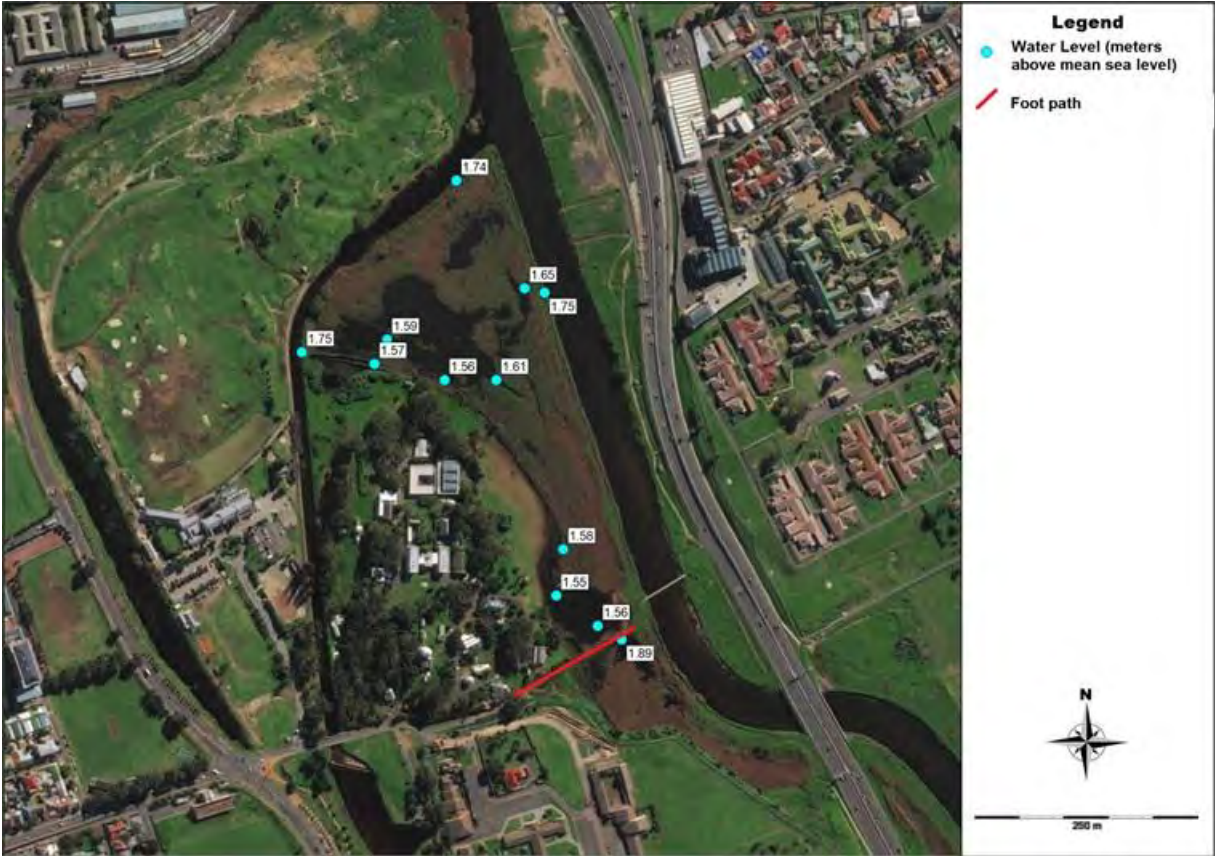


Figure 4-20 Surveyed water levels in, and surrounding, the Raapenberg wetlands

While not explicitly tested, the attenuation benefits of the wetland are clearly limited. Prior to canalisation of the rivers, the wetlands would have been far more extensive and offered significantly more attenuation capacity – unfortunately this situation is not reversible.

An interesting outcome of the analysis is that the current post development scenario would suggest that the water level would drop – albeit by 0.03 m – for the 1-year storm event. Therefore, it is possible that the proposed wider channel would offer some attenuation benefits over the existing situation for this event although this is within the margin of error and relatively insignificant. For larger storm events (greater than 1-year recurrence interval) there would be no attenuation benefit.

Effectively, the analysis indicates little to no significant change in the performance of the wetland, as long as the recent intervention is reversed.



4.5 Opportunity cost of not using the River Club for attenuation of runoff

In order to assess the opportunity cost of developing the site – instead of using it for attenuation – the City agreed previous studies could be referred to. The results of each of these is reviewed below and the implications summarised thereafter.

4.5.1 Ninham Shand (2004)

Ninham Shand (2004) investigated the idea of creating a attenuation pond by excavating high ground between the “Canalised” and “Old” Liesbeek River channels (i.e. The River Club) and along the side of Black River Parkway to provide additional flood attenuation in this area. Their analysis revealed that the 1:50 and 1:100-year flood volumes were simply too large for a pond in this area to have any attenuating effect on the downstream flow rates. It was also evident that, to be effective, significant throttling of the river flow would be required at the confluence of the Black and Liesbeek Rivers rather than just provision of additional attenuation capacity. Throttling of the river would in turn result in an unacceptable rise in flood levels in the vicinity of the River Club as well as increases in flood levels further upstream along the Liesbeek and Black Rivers. As a result, the idea of a retention pond was abandoned.

Subsequent to this study the City incorporated Climate Change and Sea Level rise into their modelling. These changes are likely to further reduce any benefits offered by an attenuation system.

4.5.2 Fisher-Jeffes (2015)

Fisher-Jeffes (2015) undertook a PhD study to assess the viability of rainwater and stormwater harvesting in South Africa. The study made use of the Liesbeek River Catchment as a case study to test the viability of rainwater and stormwater harvesting.

Fisher-Jeffes (2015) also indicated, as did Ninham Shand (2004), that providing attenuation in the region of the confluence of the Black and Salt Rivers could provide additional benefits in the form of flood attenuation. Fisher-Jeffes (2015) however only looked at records of events between 2003 and 2012 – due to the lack of data before that period. The largest recurrence interval event during this period was estimated to have been a 1:20 year event.


Fisher-Jeffes (2015) study was focused on utilising the Liesbeek River Catchment as a ‘typical’ catchment and did not model the greater Salt River Catchment as was done in Ninham Shand (2004).

4.5.3 RH-DHV (2017)

As part of the RH_DHV study two alternatives were considered for the River Club Island: either flood storage or infill and development. RH-DHV concluded that flood storage should only be considered in combination with storage at the Rondebosch and King David Mowbray golf courses or other upstream measures, as on its own it would not have a significant effect on flooding within TRUP. The effect of the combined flood storage above would have to be evaluated using a hydraulic model extending further upstream, with additional surveys of the upstream Black River cross-sections.

4.5.4 Conclusions

Based on a review of the above studies, it was apparent that the potential benefits of using the site for flood attenuation purposes would be negligible. It was also evident that the construction of an attenuation



facility would require the City to invest significant resources in design, operation and maintenance with limited benefit in terms of reduced impacts of flooding. If an alternative to flood attenuation is required it would likely be more appropriate to implement the original long-term plan of widening the channel. However, were the City to consider the potential for utilising the site to attenuate storm events, it would need to consider the following:

- The site would need to be excavated to provide additional storage.
- Additional storage / attenuation capacity would probably also have to be provided at the Rondebosch and King David Mowbray Golf Courses.
- The City would have to have the resources, to actively manage the site as either a Real-Time Control attenuation facility or a Stormwater Harvesting facility.
- The Owners of the River Club would need to be willing to sell their land, which would likely be at a high price and from which the City would not receive the financial benefits of the property rates.

Considering the above, it is unlikely, that the River Club site will be developed as an attenuation facility. Based on the available literature the benefits are unlikely to be significant - in terms of reduced flood damage.

5 Impact Assessment

Section 4 provides a detailed discussion of the potential hydrological and hydraulic impacts of the proposed development. This discussion is summarised in Section 6. The assessment of the impact was completed as shown in Table 5-1. The impact for the proposed development (any alternative) without mitigation is assessed to be insignificant, and with the proposed mitigation the impact is assessed to be low (+ve) significance. This impact is manageable to a limited extent, but once the site is develop will not be reversible.

Table 5-1 Significance of increased flood hazard

	<i>Extent</i>	<i>Intensity</i>	<i>Duration</i>	<i>Consequence</i>	<i>Probability</i>	<i>Significance</i>	<i>Status</i>	<i>Confidence</i>
<i>Both Alternatives</i>								
Without mitigation	Local	Medium	Long-term	Medium	Possible	LOW	-ve	Medium
	1	2	3	6				
Essential mitigation measures:								
<ul style="list-style-type: none"> Raise the Liesbeek Parkway locally (as discussed in Section 4.2.7) to eliminate potential High Hazard flooding at this location (at 33°56'14.80" S, 18°28'34.13" E). 								
With mitigation	Local	Low	Long-term	Low	Improbable	VERY LOW	+ve	Medium
	1	1	3	5				


In the case of the No-Go alternative, the site will continue to be used as a commercial, recreational and conference facility. There would be no change to the flood risks – except those as a result of climate change, or development on surrounding / upstream properties.

6 Conclusions

This study has reviewed seven relevant studies, and undertaken extensive modelling with both HEC-RAS and PCSWMM 2D. The site is extremely complicated, and it is necessary to consider all the separate findings together before drawing any definitive conclusions. Considering any 'question' or 'issue' raised in isolation may lead to a misinterpretation of the results. Furthermore, hydrology and hydraulic modelling should be considered as a tool for analysing potential impacts and scenarios and as this is not an 'exact science', engineering judgement and experience in interpreting the results are important. As such the findings based on the complete analysis are presented and interpreted using Aurecon's knowledge of the site. For these reasons, Aurecon involved three of its staff who have extensive experience of this site in order to ensure the analyses were undertaken and interpreted in the most appropriate manner.

Therefore, based on a review of all the available studies, the extensive modelling, and engineering judgement, it is Aurecon's opinion that:

- The results (magnitude of impact) appear to be relatively consistent for each study, even where study methods and elevations may differ slightly.
- The development of the River Club as well as the TRUP, PRASA and NRF sites is likely to have an impact on flood levels, in the order of between 0.01 m and 0.15 m depending on the storm recurrence interval and the location. The greatest differences between the results are in the vicinity of the SAAO. The impacts of these differences are insignificant.
- If the River Club is developed in isolation (i.e. TRUP, NRF, PRASA were not developed), the impacts would be of similar magnitude for all recurrence intervals, but less by approximately 0.00m – 0.03m, to the scenario where all the proposed developments went ahead. This difference is considered to be insignificant because the differences between the post development scenario's are well within the uncertainties of the modelling tools.
- It is important to note that if the TRUP, NRF, PRASA were to be developed in isolation, then the results must not be interpreted to mean that they would only have an impact equal to the difference (typically +/- 0.00m – 0.03m) between the post development scenarios including River Club, TRUP, PRASA, and the NRF sites and the post development scenario for the River Club alone – as indicated in the RHDHV Study. This is because of the complexities of the hydrology and hydraulics in the vicinity of the River Club site.
- The design of changes to the Liesbeek Canal should aim to maintain the existing hydraulic functioning of the wetland during smaller recurrence interval events. The current proposals would have little to no effect, but further detailed design refinements – during detailed design – should be reanalysed.
- It would be advisable, in consultation with the Fresh Water Consultant, to consider reversing the intervention undertaken by the TRUPA, Friends of the Liesbeek and SAAO – as this is likely to increase flows into the wetland.
- The site is unlikely to be developed by the City as an attenuation facility.
- PRASA should not be allowed to close the existing overland flood route that extends across its property, as it is important for mitigating flood risk – regardless of whether or not the proposed River Club development proceeds.
- The extension to Berkley Road should be designed in such a manner as to not impact on the water levels determined by this study and any changes to the preliminary design would need to be re-evaluated. The detailed design of the extension of Berkley Road should consider raising the portion of the road that is within the floodplain.
- There is a need to address the localised change in risk along Liesbeek Parkway. This could be done through raising the road locally (as discussed in the report) to eliminate the potential flooding by the



1 in 100 year event, however ponding due to local stormwater is also likely to occur at this location for which the provision of warning signs would probably suffice.

- The impact of the proposed development on flood levels and their extent are considered to be negligible.
- The impacts of the proposed River Club development and of the proposed Two Rivers Urban Park development on flood levels and their extent are considered to be negligible.
- Widening the Salt River Canal would reduce the flood levels for all scenarios, but that this would come at a significant cost with very little benefit and is unlikely to be in the foreseeable future.

The main conclusion of this study is that the proposed development would have an insignificant effect on flooding in the vicinity of the existing River Club site. Although the development would have some limited and localised effects on the flows and water levels in the Liesbeek and Black Rivers, the modelled impacts in terms of increased hazard and damage to properties are insignificant and can be considered negligible – as long as the above findings are appropriately dealt with.

Although the proposed development might not appear to have a significant impact on flooding, it would none the less require the following deviations in terms of the City's *'Floodplain and River Corridor Management Policy'* (CSRM, 2009a):

- Section 9.2: Flood Management and Public Safety
 - Permission to develop / obstruct the free flow of water within the 20-year flood line area would need to be granted.
- Section 10.5: Table 1: Framework for the assessment of Proposals
 - The current assessment framework forbids development (including filling) within the 50 year flood plain. It notes: *"In exceptional circumstances minor "smoothing" of the 50 / 100-year flood line may be considered, provided equivalent compensatory stage storage volume is provided within the development precinct"*.
 - As the proposed development falls under the 50-year flood line, a deviation from the policy, allowing the developer to fill (considered development) would need to be granted.

With regard to the two development layouts (Section 3.2), both would have similar impacts, although Layout Option 1 (focus of this study) would appear to be the preferable option as it aligns with the vision of the City's *'Floodplain and River Corridor Management Policy'* (CSRM, 2009a) in that, in comparison to Layout 2) it provides an improved ecological corridor, provides the potential for improved amenity and biodiversity in line with the principles of Water Sensitive Urban Design (WSUD) principles.

It is recommended that the City should take account of the findings of this study to determine whether in terms of the policy and based on consideration of the *"geomorphological, maintenance, social and economic aspects"* (presented by other specialists) the proposed development of the River Club Site should be approved.

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Appendix A

Table A1 Water Surface Elevations (mamsl) at Point 1 (Natural Ground Level = 0.389 mamsl)

Recurrence interval (Description)	Development Scenario		
	Status Quo	Post-development (River Club only)	Post-development (River Club, TRUP, NRF, PRASA)
0.5-year	1.98	1.94	1.94
1-year	2.19	2.16	2.16
2-year	2.37	2.39	2.39
5-year	2.52	2.54	2.54
10-year	2.63	2.64	2.64
20-year	2.81	2.82	2.83
50-year	2.91	2.93	2.93
100-year	2.95	2.96	2.97
200-year	3.00	Not modelled	3.01
100-year (Widened Channel)	2.79		2.8
100-year (PRASA overland route closed)	2.95		2.97
100-year (Opened Salt River mouth)	2.95		2.97

Table A2 Water Surface Elevations (mamsl) at Point 2 (Natural Ground Level = 2.651 mamsl)

Recurrence interval (Description)	Development Scenario		
	Status Quo	Post-development (River Club only)	Post-development (River Club, TRUP, NRF, PRASA)
0.5-year	No water on the surface		
1-year			
2-year			
5-year			
10-year			
20-year	2.79	2.81	2.81
50-year	2.9	2.91	2.92
100-year	2.94	2.95	2.97
200-year	3.01	Not modelled	3.01
100-year (Widened Channel)	No water on the surface		2.76
100-year (PRASA overland route closed)	2.94		2.96
100-year (Opened Salt River mouth)	2.94		2.96

Table A3 Water Surface Elevations (mamsl) at Point 3 (Natural Ground Level = 2.238 mamsl)

Recurrence interval (Description)	Development Scenario		
	Status Quo	Post-development (River Club only)	Post-development (River Club, TRUP, NRF, PRASA)
0.5-year	No water on the surface		
1-year	No water on the surface		2.27
2-year			2.41
5-year	2.76	2.79	2.84
10-year	2.90	2.9	2.91
20-year	2.97	2.97	2.98
50-year	3.02	3.03	3.03
100-year	3.05	3.06	3.07
200-year	3.05	Not modelled	3.10
100-year (Widened Channel)	2.90		2.91
100-year (PRASA overland route closed)	3.05		3.06
100-year (Opened Salt River mouth)	3.05		3.06

Table A4 Water Surface Elevations (mamsl) at Point 4 (Natural Ground Level = 0.709 mamsl)

Recurrence interval (Description)	Development Scenario		
	Status Quo	Post-development (River Club only)	Post-development (River Club, TRUP, NRF, PRASA)
0.5-year	2.16	2.17	2.17
1-year	2.51	2.52	2.51
2-year	2.77	2.79	2.79
5-year	3.04	3.06	3.06
10-year	3.18	3.19	3.2
20-year	3.31	3.33	3.33
50-year	3.42	3.43	3.44
100-year	3.47	3.48	3.48
200-year	3.52	Not modelled	3.52
100-year (Widened Channel)	3.11		3.12
100-year (PRASA overland route closed)	3.48		3.49
100-year (Opened Salt River mouth)	3.47		3.48

Table A5 Water Surface Elevations (mamsl) at Point 5 (Natural Ground Level = -0.374 mamsl)

Recurrence interval (Description)	Development Scenario		
	Status Quo	Post-development (River Club only)	Post-development (River Club, TRUP, NRF, PRASA)
0.5-year	2.48	2.49	2.49
1-year	2.84	2.85	2.85
2-year	3.2	3.24	3.24
5-year	3.58	3.61	3.62
10-year	3.83	3.86	3.88
20-year	4.11	4.14	4.16
50-year	4.44	4.49	4.52
100-year	4.64	4.68	4.71
200-year	4.81	Not modelled	4.88
100-year (Widened Channel)	3.58		3.49
100-year (PRASA overland route closed)	4.67		4.75
100-year (Opened Salt River mouth)	4.64		4.71

Table A6 Water Surface Elevations (mamsl) at Point 6 (Natural Ground Level = 3.443 mamsl)

Recurrence interval (Description)	Development Scenario		
	Status Quo	Post-development (River Club only)	Post-development (River Club, TRUP, NRF, PRASA)
0.5-year	No water on the surface		Developed as part of TRUP Proposal
1-year			
2-year			
5-year			
10-year			
20-year	3.84	3.72	
50-year	4.49	4.52	
100-year	4.69	4.75	
200-year	4.85	Not modelled	
100-year (Widened Channel)	No water on the surface		
100-year (PRASA overland route closed)	4.71		
100-year (Opened Salt River mouth)	4.69		

Table A7 Water Surface Elevations (mamsl) at Point 7 (Natural Ground Level = -0.23 mamsl)

Recurrence interval (Description)	Development Scenario		
	Status Quo	Post-development (River Club only)	Post-development (River Club, TRUP, NRF, PRASA)
0.5-year	2.48	Section of 'Old' Liesbeek filled	
1-year	2.84		
2-year	3.21		
5-year	3.63	3.61	3.62
10-year	3.88	3.86	3.88
20-year	4.16	4.14	4.17
50-year	4.49	4.52	4.53
100-year	4.69	4.75	4.76
200-year	4.85	Not modelled	
100-year (Widened Channel)	3.84		
100-year (PRASA overland route closed)	4.71		
100-year (Opened Salt River mouth)	4.69		
			4.76

Table A8 Water Surface Elevations (mamsl) at Point 8 (Natural Ground Level = -0.492mamsl)

Recurrence interval (Description)	Development Scenario		
	Status Quo	Post-development (River Club only)	Post-development (River Club, TRUP, NRF, PRASA)
0.5-year	2.53	2.52	2.52
1-year	2.92	2.89	2.89
2-year	3.28	3.29	3.29
5-year	3.63	3.66	3.67
10-year	3.88	3.92	3.94
20-year	4.15	4.20	4.22
50-year	4.48	4.55	4.58
100-year	4.68	4.74	4.77
200-year	4.85	Not modelled	
100-year (Widened Channel)	3.81		
100-year (PRASA overland route closed)	4.71		
100-year (Opened Salt River mouth)	4.68		
			4.77

Table A9 Water Surface Elevations (mamsl) at Point 9 (Natural Ground Level = 1.379 mamsl)

Recurrence interval (Description)	Development Scenario		
	Status Quo	Post-development (River Club only)	Post-development (River Club, TRUP, NRF, PRASA)
0.5-year	2.54	2.56	2.56
1-year	2.97	2.95	2.95
2-year	3.33	3.36	3.37
5-year	3.65	3.75	3.76
10-year	3.89	3.99	4.01
20-year	4.17	4.26	4.28
50-year	4.49	4.58	4.62
100-year	4.69	4.77	4.80
200-year	4.85	Not modelled	4.98
100-year (Widened Channel)	3.90		4.24
100-year (PRASA overland route closed)	4.72		4.84
100-year (Opened Salt River mouth)	4.69		4.80

Table A10 Water Surface Elevations (mamsl) at Point 10 (Natural Ground Level = 3.299mamsl)

Recurrence interval (Description)	Development Scenario		
	Status Quo	Post-development (River Club only)	Post-development (River Club, TRUP, NRF, PRASA)
0.5-year	No water on the surface		
1-year			
2-year	3.33	3.36	3.36
5-year	3.65	3.75	3.76
10-year	3.89	3.99	4.01
20-year	4.17	4.26	4.28
50-year	4.49	4.58	4.62
100-year	4.69	4.77	4.8
200-year	4.69	Not modelled	4.98
100-year (Widened Channel)	4.85		4.23
100-year (PRASA overland route closed)	4.72		4.84
100-year (Opened Salt River mouth)	4.69		4.80

Table A11 Water Surface Elevations (mamsl) at Point 11 (Natural Ground Level = 1.974 mamsl)

Recurrence interval (Description)	Development Scenario		
	Status Quo	Post-development (River Club only)	Post-development (River Club, TRUP, NRF, PRASA)
0.5-year	2.55	2.57	2.57
1-year	2.96	2.96	2.96
2-year	3.35	3.38	3.39
5-year	3.69	3.81	3.81
10-year	3.93	4.05	4.07
20-year	4.20	4.29	4.32
50-year	4.51	4.59	4.63
100-year	4.70	4.77	4.81
200-year	4.86	Not modelled	4.99
100-year (Widened Channel)	4.17		4.44
100-year (PRASA overland route closed)	4.72		4.84
100-year (Opened Salt River mouth)	4.70		4.81

Table A12 Water Surface Elevations (mamsl) at Point 12 (Natural Ground Level = 1.206 mamsl)

Recurrence interval (Description)	Development Scenario		
	Status Quo	Post-development (River Club only)	Post-development (River Club, TRUP, NRF, PRASA)
0.5-year	2.69	2.67	2.67
1-year	3.11	3.10	3.10
2-year	3.41	3.42	3.42
5-year	3.71	3.74	3.75
10-year	3.95	3.99	4.01
20-year	4.22	4.27	4.29
50-year	4.54	4.60	4.64
100-year	4.74	4.80	4.83
200-year	4.90	Not modelled	5.00
100-year (Widened Channel)	4.05		4.04
100-year (PRASA overland route closed)	4.76		4.86
100-year (Opened Salt River mouth)	4.74		4.83




Appendix B



Legend

- Status quo 0.5yr
- Post_development 0.5yr



A north arrow is positioned above a scale bar labeled '1 km'.

Figure B1 Comparison of 0.5-year flood inundation extents (Status Quo Vs Post Development with River Club, TRUP, NRF, PRASA)

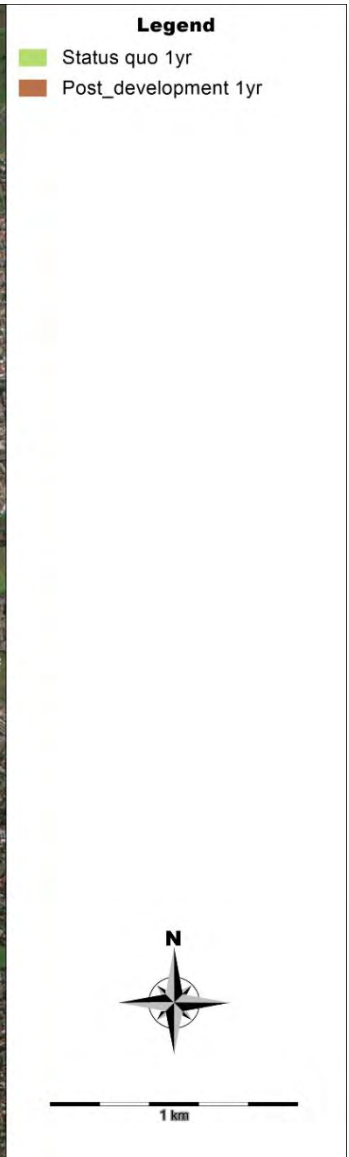


Figure B2 Comparison of 1-year flood inundation extents (Status Quo Vs Post Development with River Club, TRUP, NRF, PRASA)

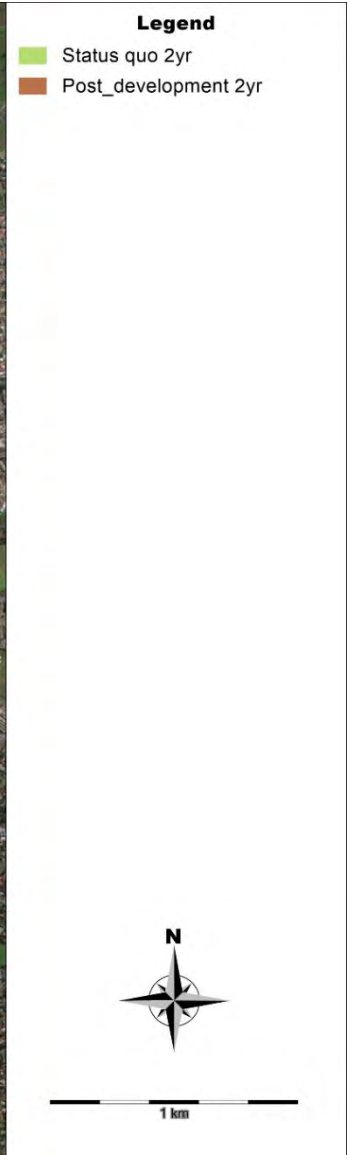


Figure B3 Comparison of 2-year flood inundation extents (Status Quo Vs Post Development with River Club, TRUP, NRF, and PRASA)



Legend

- Status quo 5yr
- Post_development 5yr

N

1 km

Figure B4 Comparison of 5-year flood inundation extents (Status Quo Vs Post Development with River Club, TRUP, NRF, and PRASA)

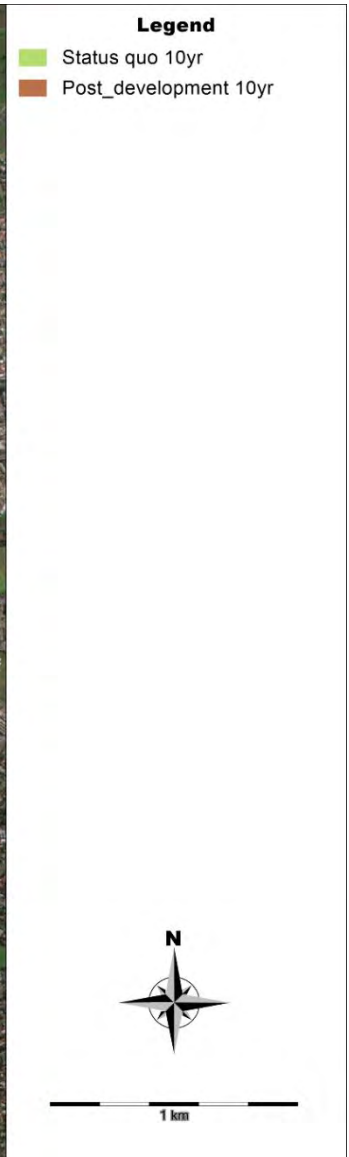


Figure B5 Comparison of 10-year flood inundation extents (Status Quo Vs Post Development with River Club, TRUP, NRF, and PRASA)



Legend

- Status quo 20yr
- Post_development 20yr

N

1 km

Figure B6 Comparison of 20-year flood inundation extents (Status Quo Vs Post Development with River Club, TRUP, NRF, and PRASA)



Figure B7 Comparison of 50-year flood inundation extents (Status Quo Vs Post Development with River Club, TRUP, NRF, and PRASA)



Legend

- Status quo 100yr
- Post_development 100yr

N

1 km

Figure B8 Comparison of 100-year flood inundation extents (Status Quo Vs Post Development with River Club, TRUP, NRF, and PRASA)



Aurecon South Africa (Pty) Ltd

Reg No 1977/003711/07

Aurecon Centre
1 Century City Drive
Waterford Precinct
Century City
Cape Town 7441
PO Box 494
Cape Town 8000
South Africa

T +27 21 526 9400

F +27 21 526 9500

E capetown@aurecongroup.com

W aurecongroup.com

Aurecon offices are located in:

Angola, Australia, Botswana, China,
Ghana, Hong Kong, Indonesia, Kenya,
Lesotho, Macau, Mozambique,
Namibia, New Zealand, Nigeria,
Philippines, Qatar, Singapore, South Africa,
Swaziland, Tanzania, Thailand, Uganda,
United Arab Emirates, Vietnam.